PLATING AND BOILER-MAKING

Joseph Horner

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PLATING AND BOILER-MAKING

A PRACTICAL HANDBOOK FOR WORKSHOP OPERATIONS

INCLUDING

AN APPENDIX OF TABLES

BY

JOSEPH G. HORNER, A.M.I.M.E.

AUTHOR OF "LOCKWOOD'S DICTIONARY OF MECHANICAL ENGINEERING TERMS," "METAL TURNING," "PRACTICAL IRONFOUNDING," "MILLING MACHINES," "TOOLS," ETC.

SECOND EDITION, THOROUGHLY REVISED AND ENLARGED

With Three Hundred and Fifty-one Illustrations

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PREFACE.

THE original articles upon which this volume is based appeared in the *English Mechanic*, but many extensions and improvements have been introduced into the present work. All of the chapters have been more or less amplified,—some to a very large extent,—and thirty-six new drawings have been prepared. Two new chapters on "The Marking out of Work," and on "The Estimation of Weights," have been written. The subject of Machine Riveting has been treated rather fully. Illustrations of most of the principal types of the machines used by platers and boiler-makers have been introduced, with brief descriptions of the same; and an Appendix of Useful Tables has been included.

I have been in intimate contact with the boiler-shop during the greater portion of my life, and the book is therefore naturally written wholly from the practical standpoint, primarily for the apprentice and workman. The trade and its tools occupy the first two chapters. The characteristics of the materials used, their common tests for quality, the dimensions and sections of plates, bars, angles, &c., occupy three chapters. Three chapters are devoted to the cutting, straightening, and bending of plates, angles, &c. A chapter is devoted to welding, one to flanging, one to punching, and one to riveting—which last includes descriptions of the methods of hand and of machine riveting. The principal types of riveted joints are described in the chapter following. The troublesome subject of the estimation of the lengths of material for given jobs is

treated of by itself. One chapter is given to the drawing and marking out of work, and one to the estimation of weights. A general account of the principal types of machines in use occupies the final chapter. The Appendix is lengthy, and comprises tables which are of everyday service in the workshop.

The result is, I trust, a volume which is a more complete and full companion to the trade than any yet published.

It should also be of value to the student who, having mastered much theoretical knowledge, is yet unacquainted with the everyday practice of our shops.

J. H.

NOTE TO THE SECOND EDITION.

THE First Edition of this work having been exhausted, I have taken the opportunity to revise certain portions. Those which relate to the commercial sizes and tests of steel have been rewritten. Recent machines have been introduced. The old cut blocks have been discarded in favour of half-tone blocks. Several new line drawings have been introduced. It is hoped that the work will continue to be received with favour by that section of the engineering trade to which it specially appeals.

J. H.

BATH, 1908.

CONTENTS.

CHAPTER I.

THE TRADE.

PAGE

Subdivision of Work in the Trade.—The Plater.—The Angle-Iron-smith.—The Riveter.—Learning the Trade.—Wages.—Isolation of the Trade.—Its comparatively Recent Development.—Its Literature 1

CHAPTER II.

TOOLS.

Chisels.—Setts.—Flatters.—Set Hammer.—Fullers.—Tongs.—Hammers.—Mallet.—Caulking Tools.—Rivet Sett.—Rivet Punch.—Drifts.—Spanner and Podger.—Centre Punch.—Centring Tool.—Trammels.—Compasses.—Dividers.—Scriber.—Dividing Wheel.—Scrape.—Snap.—Dollys.—Calipers.—Clamp.—Drills 6

CHAPTER III.

MATERIALS.

Iron and Steel.—Diversity in Quality.—Sectional Forms.—Wrought-Iron.—Method of its Production.—Stages of Puddling.—Piling.—Want of Homogeneity.—Mild Steels.—Method of their Production.—Open Hearth.—Bessemer.—Comparison between Iron

and Steel.—Lamination.—Blisters.—Strength as shown by Test Pieces.—Ductility.—Direction of Fibre, or "Grain."—Limiting Sizes.—Relation of Strength to Ductility.—Copper.—Impurities in Ore.—Strength as Affected by Temperature.—Its Employment by Boiler-makers.—How Worked . . . . . PAGE 24

CHAPTER IV.

TESTING MATERIALS.

The Tensile Test.—Maximum and Minimum Strength.—Breaking Strength, and Elongation before Fracture.—The Elastic Limit.—Stress-Strain Diagram.—Standard Test Pieces.—Iron Plates.—Various Qualities.—Tensile Tests.—Forge Tests.—Nicking Test for Fibre.—Section Irons.—Forge Tests.—Hot and Cold.—Mild Steel.—Various Qualities.—Tensile Tests.—Forge Tests.—Hot and Cold 40

CHAPTER V.

LIMITING DIMENSIONS AND WEIGHTS OF MATERIALS.

Maximum Dimensions.—Plates,—Area, Length, Width.—Extras.—Lists. — Dimensions of Rolled Sections. — Extras. — United Inches 60

CHAPTER VI.

CUTTING AND STRAIGHTENING PLATES, &c.

Shearing Machines.—Cold Iron Saws.—Ordering Plates.—Sketch Plates.—Sawing Angles, &c.—Cutting Block.—Planed Edges.—Cutting Curved Edges.—Levelling Blocks.—Straightening Plates with the Hammer.—Details of the Process.—Straightening in Rolls.—Straightening Section Irons.— Details.— Straightening Machine 70

CHAPTER VII.

BENDING PLATES.

PAGE

The Reverberatory Furnace.—The Bending Rolls.—Their Method of Action.—Their Essential Imperfections.—Descriptions of their Gearing.—Bending Rings.—Bending Conical Forms.—Bending Sections of Plates.—Bending Envelopes of Spheres.—The Use of Templets.—Bending Blocks.—Various Types . . . 92

CHAPTER VIII.

BENDING ANGLES, &c.

Type of Forge used for Heating Work.—Anvil.—Block for Levelling and Bending. — Stand for Small Blocks. — Various Blocks.—Conical Stand.—Method of Bending Easy Curves.—Method of Bending Quick Curves.—Bending Internal Angles.—Bending External Angles.—Bending of Small Rings.—Limits to Curvature Imparted.—Rig-up of Small Blocks.—Bending Angular Forms.—Crinkling. — Notching for Welding Corners. — Bending of Tees.—Bending of Rails.—Bending of Foundation Ring.—Bending of Man-hole Ring.—Machine for Bending Angle Irons.—Furnace for Heating Angles 115

CHAPTER IX.

WELDING.

Differences in Welding as done by Smiths and by Boiler-makers.—Making Hollow Fires with Bricks.—The Heat for Welding.—The Scarfed Form of Weld.—Man-hole Ring.—Fire-hole Ring.—The Glut Form of Weld.—Foundation Ring.—Rigs-up for same. — Angle Iron Rings. — Rigs-up for same. —Angle Iron Frames. — Scarfed Joints. — Rigs-up. —Burrs. — Glut Joints. — Welds in Tubes. — Lap Welds. — Glut Welds. — Mandrels. — Portable Furnace.—Portable Anvil.—Rig-up for Tubes . . 152

CHAPTER X.

FLANGING.

PAGE

Difference between Bending and Flanging.—Flanging in General.—Setting Down.—Flanging Flat Rectangular Plates.—Rigs-up.—Flanging Circular Plates.—Rigs-up.—Checking Accuracy of Flanges.—Flanging Tubes.—Rigs-up.—Checking Flanges.—Setting out Fire-box Shell.—Adamson Seams.—Flanging Machines 184

CHAPTER XI.

PUNCHING.

Marking Holes for Punching.—Whitening Plates.—Marking Centre Lines and Circles.—Centre Popping.—Machines.—Operation of Plates under the Punch.—Supporting Beams.—Sling Chains and Bars.—Stands.—Punches and Dies, or Bolsters.—Proportions and Taper of.—Necessity of keeping Cutting Edges Keen . . 203

CHAPTER XII.

RIVETING.

Placing of Plates for Riveting.—Reamering Punched Holes.—Sets of Riveters.—Division of the Work.—Holding-up Hammer.—Caulking.—Caulking Plates and Rivets.—Tanks.—Cutting out Rivets.—Iron and Steel Rivets.—Countersunk Rivets—Proportions of Rivets.—Machine and Hand Riveting compared.—Hydraulic Riveting.—Pneumatic Riveting.—Rivet Furnace.—Description of Hydraulic Riveting Plant 212

CHAPTER XIII.

TYPES OF RIVETED JOINTS.

Lap Joints.—Thinning Corners.—Joints made with Covering Strips.—Joints made with Angle Iron.—Flanged Joints.—Furnace Tubes.—Girder Work.—Compound Girders.—Built-up Girders.—The Single Girder.—Joints in Long Girders.—The Double Girder.—Heaters.—Division of Girders.—Brackets.—Jointing Vertical Members.—Diagonal Members 237

CHAPTER XIV.

ESTIMATION OF LENGTHS OF MATERIAL.

PAGE

Variation due to Modes of Working.—Shop Rules for Plain Circular Rings.—For Angle Iron Rings.—External and Internal.—For Tee Iron Rings.—Elliptical Rings.—Prices of Work Per Ton.—For Riveting.—For Flanging.—For Bending and Welding Angle Irons.—For Cross Tubes 258

CHAPTER XV.

THE MARKING OUT OF WORK.

Mostly Marked to Full Size.—Reasons why Necessary.—Methods Employed.—Depends on Size of Work.—Geometrical Methods Required.—Errors in Rule Measurement.—Methods of Transferring Dimensions.—Development of Surfaces.—Telescopic Plates.—Curves of large Radii.—Envelope of Conic Frustrum.—Fitting of Cylindrical Parts.—Development of Envelopes of Spheres.—Of Conical Water Tube.—Drawing an Ellipse . . 265

CHAPTER XVI.

THE ESTIMATION OF WEIGHTS, &c.

Estimates for Cost of Work.—Based on Weights.—Direct Method of Calculation of Weights.—Calculations based on Tables.—Weighing a Unit Piece, Unit Measurements, and Multipliers.—Cubic and Superficial Measurements.—The Geometrical Forms of Material.—How to Utilise Tables.—Useful Multipliers.—Relative Weights.—Estimation of Rivets.—Mensuration.—Of Plane Figures.—Parallelograms.—The Use of Decimals.—Triangles.—Quadrilaterals.—Trapezoids.—Polygons.—Circles.—Circular Rings.—Sector.—Segment.—Enveloping Surfaces.—Of Cylinder.—Sphere.—Zone of Sphere.—Volumes.—Of Rectangular Body.—Parallelogram.—Cylinder.—Annular Vessel.—Pyramid.—Cone.—Sphere.—Methods adopted for Simplifying Calculations.—Averaging 283

CHAPTER XVII.

MACHINES.

PAGE

Increase in Capacity and Weight.—Plate-Edge Planing Machines.—Bending Rolls.—Flattening Rolls.—Punching and Shearing Machines—Methods of Operation.—Light and Heavy Machines.—Horizontal Machines.—Combined Machines —Multiple Punching Machines.—Drilling Machines—Various Kinds.—Boiler Shell Drilling Machines.—Boiler Flue Drilling Machines.—Portable Drilling Machines.—Countersinking.—Flanging Machines.—Angle-Iron Bevelling Machine.—Riveting Machines.—Pneumatic Chipping and Caulking.—Rivet Furnaces.—Cold Iron Saws.—Welding Hammers 295

APPENDIX 329

INDEX 367

LIST OF TABLES.

PAGE

TABLE I. 39

Experiments made at the Franklin Institute, America, in connection with an Investigation into the Strength of Boilers, to show the Diminution of Strength which Copper undergoes with Increase of Temperature.

TABLE II. 47

Summary of Tests of Iron and Steel Plates (*vide* Merchant Shipping Experiments on Steel).

TABLE III. 52

Test of Elastic and Ultimate Tensile Stresses in Steel Plates (*vide* Merchant Shipping Experiments on Steel).

TABLE IV. 52

Showing Ductility in Steel Plates (*vide* Merchant Shipping Experiments on Steel).

TABLE V. 60

Maximum Dimensions of Steel Plates rolled by John Brown & Co.

TABLE VI. 62

Maximum Dimensions of Iron Boiler Plates and Sheets rolled at the Snedshill Iron Works.

TABLE VII. 157

To Estimate Temperature roughly by the Appearance of Metal.

PAGE

TABLE VIII. 157

To Estimate Exact Temperatures by the Fusion of Substances.

TABLE IX. 331

Proportions of Riveted Joints.

TABLE X. 331

Proportions of Riveted Joints.

TABLE XI. 332

Proportions of Riveted Joints.

TABLE XII. 332

Proportions of Riveted Joints.

TABLE XIII. 333

Proportions of Riveted Joints.

TABLE XIV. 333

Proportions of Riveted Joints.

TABLE XV. 334

Proportions of Riveted Joints.

TABLE XVI. 334

Proportions of Riveted Joints.

TABLE XVII. 335

Riveting for Tank Work.

TABLE XVIII. 335

Bolt Centres in Angle Irons.

PAGE

TABLE XIX. 336

Diameters, Circumferences, Areas, Sides of Equal Squares, Squares, and Cubes.

TABLE XX. 350

Standard Sheet and Hoop Iron Gauge.

TABLE XXI. 351

Weight of Iron, Steel, and Copper Plates.

TABLE XXII. 352

Weight of Flat Bar Iron and Steel.

TABLE XXIII. 356

Weight of Round Bars of Iron and Steel.

TABLE XXIV. 357

Weight of Square Bars of Iron and Steel.

TABLE XXV. 358

Weight of Angle and Tee Iron.

TABLE XXVI. 360

Weight of Angle and Tee Steel.

TABLE XXVII. 363

Table to Facilitate the Calculation of the Number of Rivets of a given Pitch in a given Length.

TABLE XXVIII. 363

Fractional Parts of a Pound Avoirdupois, and their Decimal Equivalents.

PAGE

TABLE XXIX. 364

Fractional Parts of an Inch and their Decimal Equivalents.

TABLE XXX. 365

Inches and Parts and their Equivalent Decimals of a Foot.

TABLE XXXI. 366

Comparative Weights of Different Bodies.

PLATING & BOILER-MAKING.

CHAPTER I.

THE TRADE.

Subdivision of Work in the Trade.—The Plater.—The Angle-iron Smith.—The Riveter.—Learning the Trade.—Wages.—Isolation of the Trade.—Its Comparatively Recent Development.—Its Literature.

Subdivision of Work in the Trade.—Plating and boiler-making are usually carried on now as two distinct trades, and should, therefore, form the subject-matter of two distinct volumes. But, on the other hand, the two classes of work are so interdependent, and overlap one another so extensively, that it is not judicious to treat them separately. And since this volume must be of an elementary and fundamental character only, dealing more with principles than details, more with cardinal types and methods than with elaborate structures, I think that it is quite necessary to consider plating and boiler-making as one and the same essential trade. And, indeed, they were so not many years since, within my recollection, and I have known, and still know, men who can do anything, who have worked at plating and girder work, and who have worked at the construction of every modern type of boiler. Moreover, it is not possible to be a complete boiler hand without a knowledge of plating, notwithstanding that a plater may now be quite unable to work on some portions of boilers, and a boiler hand may become so specialised as to be very awkward if put to some classes of plating. But, indeed, if I were to subdivide my subject as the trade is at present subdivided, I should want not two divisions, but eight or ten. For in a modern shop men are templet-makers, platers, riveters. angle-iron smiths;

and in shops still more specialised there will be caulkers, tubers, flangers, and so on. Moreover, some shops stick to one class of work only or chiefly, perhaps bridge, girder, and roof work; while of boiler shops proper one may do nothing but locomotive work, another Cornish and Lancashire boilers, another chiefly verticals, another marine, and so on. And then also a deal of the work is done by labourers or attendants at machines. In this way the all-round boiler-maker, like the fitter, the joiner, and others, is becoming a relic of the past.

Discarding, however, these minute divisions which obtain in the larger shops, we may say that the practice of the trade in the smaller shops recognises and demands three main classes of workmen—platers, angle-iron smiths, and riveters, all being men capable of making bridge and girder and roof work, and boilers.

The Plater.—A plater works chiefly upon plates and flat bars. He must know how to mark out work, for which a knowledge of geometry, of projection, and development of surfaces is necessary. In large shops, however, he may not have to mark out at all, because a man is usually kept for that purpose, and for marking off templets; hence called a "marker out" or "templet marker." Still, a plater is supposed always to be able to mark out his own work. He has also to level plates under the hammer, or in the rolls, and to do such bending as is necessary. Usually, too, though not always, he will do shearing, and punching, and shaping generally, until the work is ready for the riveter.

The Angle-iron Smith.—The angle-iron smith is considered the most important man in a boiler shop, good craftsmen in this line being usually most difficult to obtain. There is a lot of troublesome work involved in bending, bevelling, and welding angle, tee, and channel irons, and this is the work which is done by the angle-iron smith.

The Riveter.—The riveter takes the prepared plated and angle-iron work, and, as his name implies, rivets it up together, and caulks it. There is no special difficulty in doing this; but it often involves working in constrained and awkward positions, and as prices are fixed by piecework, there is little margin of time left to waste. Moreover, riveting machines are largely superseding hand-riveting, and less skilled labour is therefore required. For outdoor work, platers or riveters, or both, are usually sent.

Although the work of the boiler-shop is thus divided between three classes of craftsmen, yet a good hand should be able to do either branch of the trade if required. For these branches are intimately connected, and are interdependent. And in learning the trade, time and opportunity should be afforded to lads to acquire a knowledge of each branch, and here again lies one of the advantages which country shops have over the mammoth establishments. In the country a lad works in turn with different sets of men—both in the shops and out-of-doors —and so has opportunity, if he is keen and alert, to pick up a knowledge of each branch.

Learning the Trade.—The usual method of learning the trade is to begin as a rivet-boy. His duties consist in heating the rivets at the furnaces, and bringing them to the men. He also makes himself useful in many ways—in holding on, holding up—afterwards in putting in rivets, and hammering or snapping. Then he will be given plain plating to mark out, and to shear or punch ; afterwards he may go to the fire and do plain smithing, and finally welding. He will gradually be trusted with odd simple jobs to carry through, and experience will do the rest.

Wages.—The wages paid to boiler-makers average more than those paid to men in other branches of engineering—perhaps from six to eight shillings more, according to locality. As a set-off against this advantage, there is the disagreeable character of the trade. The work is hard, often hot and noisy. Many boiler-makers become more or less permanently deaf before middle life. Still, for men who really like it, there is much of interest to be learned, and the prizes are good. Most of the work is done by the piece, and good men will often average from 50s. to 60s. weekly. The day wages of riveters will average from 32s. to 34s. weekly ; those of platers, 36s. to 38s. ; those of angle-iron smiths, 38s. to 42s. In iron shipbuilding, large sums are earned by men working by contract, frequently from 15s. to 20s. per day. But this work is fluctuating. Foremen in large shops also get paid well, for the responsibility is heavy, and good men are not easily obtained. Inspectorships also are sometimes open to good men.

Isolation of the Trade.—There is little similarity between plating and boiler-making and the other branches of engineering. It stands apart, much as iron and brass founding does. There are many engineers' shops without a boiler shop,

as there are also many without a foundry. Plenty of engineers think they can buy boilers cheaper than they can make them. In country shops, however, a boiler shop is almost a necessity, since a good deal of repair work can be picked up. But in any case, the boiler shop is a department practically isolated from the others. Its materials and methods have little kinship with the materials and methods which pertain to the other shops. Its cousin-german is the smithy. But though materials are similar, the forms of the materials and the methods of their working up are essentially distinct, so much so, that a smith could not do plating and boiler work, neither could the plater compete with the smith at the forge.

Comparatively Recent Development of the Trade.—Plating and boiler-making is a trade of comparatively recent development. The craft of the smith dates back perhaps a couple of millenniums; that of the plater and boiler-maker is not yet a century old. The earlier steam boilers were made of cast-iron; the earlier wrought-iron boilers are not more than seventy or eighty years old at the outside. We may see plenty of them now of the haystack and egg-ended type in the Black Country, still in use. As for plated work in wrought-iron and mild steel, it has practically come in with the present generation. The early railway engineers used cast-iron for girders for bridge work and for other structural work, which is now done in wrought-iron and steel. Bridges and roofs and ships now made of iron and steel were not long since made of timber. The inventions of the Bessemer and Siemens steels have given such an impetus to the use of mild steel plates and bars in all kinds of structural work, that the work of the plater has become of vastly more importance and of greater extent than formerly. The successful introduction of mild steel has resulted in very extensive applications of that material to many classes of work for which even wrought-iron was not well adapted. So that many structures are now built up of plates and sheets, with angles and other sections, that were formerly made more clumsily in other materials. In the course of thirty years plating has developed from a relatively lesser industry into one of quite national and international importance.

The prospects of the trade are therefore good. It not only cannot be superseded, but its practice has largely supplanted the use of cast-iron and timber. In this respect plating compares very favourably with many trades which are falling into a

more or less moribund condition, and but for its disagreeable character, many more men would doubtless be attracted to it.

Literature.—The literature of plating and boiler-making is, however, in its infancy. An immense number of experiments relating to the strength of plates, bars, and structures have been made and recorded, and the results have been embodied in tables for the use of designers. A large number of machines have been devised and perfected for quickening the operations of the shops. But not much has been done to aid the technical student, the apprentice, and the workman. I propose, therefore, to consider plating and boiler-making from their point of view; to look at the subject from the standpoint of the workshop; to consider the main principles involved, and the leading elements and details of practice. For many years my duties have necessitated my being in constant contact with the work of the boiler-shop; and I trust, therefore, that what I shall say will be of service to many who have not enjoyed these opportunities of gathering prolonged and varied experience in plating and boiler work.

CHAPTER II.

TOOLS.

Chisels.—Setts.—Flatters.—Set Hammer.—Fullers.—Tongs.—Hammers.—Mallet.—Caulking Tools.—Rivet Sett.—Rivet Punch.—Drifts.—Spanner and Podger.—Centre Punch.—Centring Tool.—Trammels.—Compasses.—Dividers.—Scriber.—Dividing Wheel.—Scrape.—Snap.—Dollys.—Calipers.—Clamp.—Drills.

Tools.—I will briefly run over the names and uses of the more common tools used in plating and boiler work. Some special tools and various useful appliances will be described in subsequent chapters. In this I shall only take the more important of those tools which are universally employed. They are not numerous, but are mostly of a character special to the trade. Some, however, are used by smiths also.

Chisels.—Taking the cutting tools, we have chisels and setts of various forms. The chisels are of the same general type as those which are used by fitters. Fig. 1 shows the ordinary cold chisel drawn proportionately. But Fig. 2 is a modified form used as much as the other, and almost exclusively by boiler-makers. Its cutting edge is convex transversely. It is shorter than the engineer's chisel, and its cutting angle is also rather obtuse. This type of chisel is used for dressing round the edges of hand-holes, mud-holes, man-holes, and fire-holes. Since most of this chipping has to be done in a diagonal direction, the reason is apparent why a short chisel ground to considerable curvature is desirable. Fig. 3 is a common cross-cut chisel; Fig. 4 is called a sett, and sometimes a cross-cut chisel. It is used for nicking round holes in thin plates, cutting across a piece of thin plate to facilitate its division, cutting pieces out of boilers for the insertion of new pieces of plates, &c. Fig. 5A is a gouge, or cow-mouthed

chisel, employed for hollow cutting generally. Fig. 5B is a round nose, a form of sett used for purposes similar to Fig. 4.

Setts.—The cold and hot setts with handles are used for the various operations of the forge. The difference in the

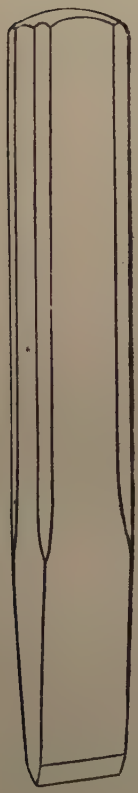


FIG. 1.

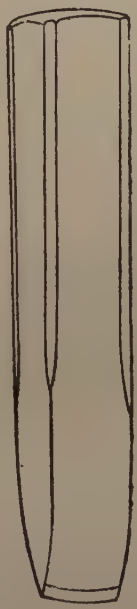


FIG. 2.

FIG. 3.

two types is, that the first named is thick, or relatively obtuse, in order that it shall stand the stress of cutting cold metal, Fig. 6; the second is comparatively thin, and ground more

acutely, Fig. 7, for cutting hot metal. These are struck by the sledge. Fig. 8 shows a cold sett handled with hazel rod, a method alternative with that shown in Fig. 6. Both the chisels and the gouges or hollow setts are made with thick

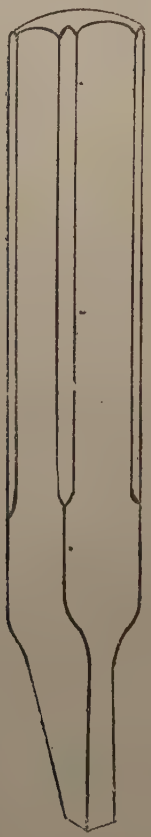


FIG. 4.

FIG 5A.

FIG. 5B.

and thin cutting edges. Fig. 9 illustrates one of the gouges or hollow setts. These are not only made for cutting hot and cold metal, but are also of many curvatures, and also with one bevel, and with two. These are the only types of cutting

tools operated by hand which are used by boiler-makers. The flatters, fullers, and swages, however, are numerous, and will number several dozens to a forge. They are referable to a few broad types, as follows :—

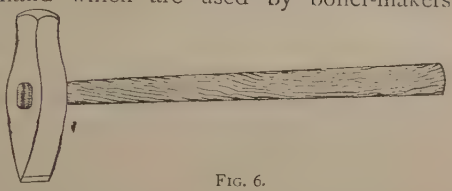


Fig. 6.

Flatters.— The flatters are seen in Figs. 10 to 12. Fig. 10 shows the common type, handled rigidly; Fig. 11 the same, with a moderately flexible handle. Each is struck with the sledge. The first is chiefly used on work at the anvil, the second on work at the levelling block, and in situations where the work is placed rather lower down than it is on the anvil. Still the two types are used somewhat indiscriminately on all classes of jobs. The advantage of Fig. 11 is that when the work is low down the smith can hold the handle at a suitable height without stooping inconveniently at his tasks.

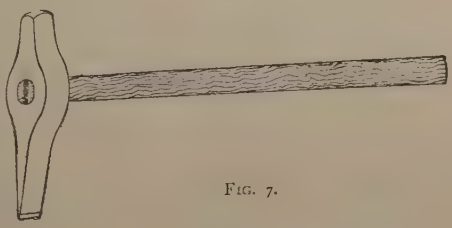


Fig. 7.

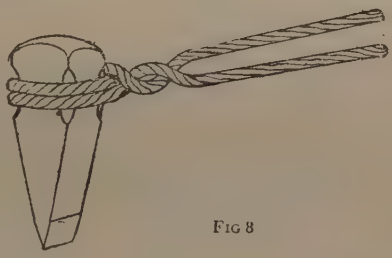


Fig 8

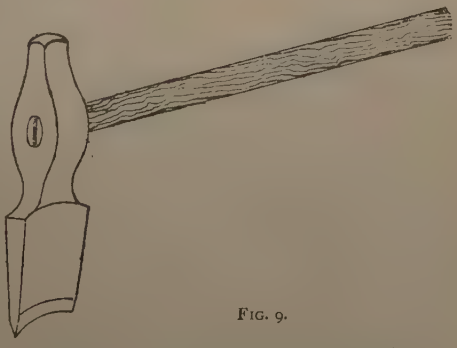


Fig. 9.

The iron rods can be bent to suit surfaces situated higher or

lower. Also there is less jar on the hands from the blows of the sledge with the comparatively elastic rods than with the rigid handle in Fig. 10. The rod, it will be noted, is twisted round the neck of the flatter, the free ends brought underneath the wood, turned up and carried through the handle and clinched, and loops or couplers of iron bound round in two places. The attachment is thus rendered perfectly secure. A modification of the ordinary flatter is shown in Fig. 12. It is extended in front for $1\frac{1}{2}$ in. or 2 in. beyond the usual length, so making it of an oblong form. This is used for finishing off the inner faces of angle irons and channels when an angle or a flange above would not permit of the sledge being brought down upon the top of the ordinary flatter. The head of the oblong flatter is, therefore, well outside the angle or channel, as the case may be, in a position to receive the hammer-blows from above, while the projecting end of the flatter lies on the inner face of the flange.

FIG 10.

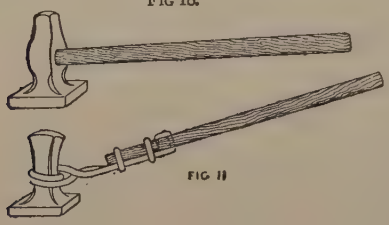


FIG 11

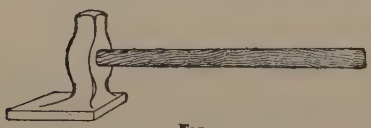


FIG. 12.

Set Hammer.—A somewhat similar tool to the flatters, differing therefrom chiefly in the narrower face, is the set hammer, Fig. 13. It is not used so much by boiler-makers as the flatter, the latter being better adapted to the broad surfaces which are generally operated on. It is of occasional use, however, in setting down shoulders on angles, tees, and bars. It is struck with the sledge.

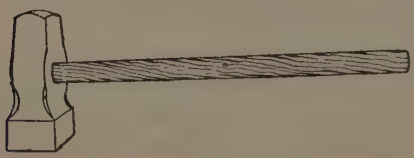


FIG. 13.

Fullers.—By an easy transition we pass from the flatters to the fullers. Thus, Fig. 14 may be called either a round-

face flatter or a flat fuller. The curvature may run in the direction of the longitudinal axis of the hammer-shaft, or transversely thereto, as in the figure, each form being required for different classes of work. Either may be handled with rigid handles, as in the figure, or with wire rods, like Fig. 11. The amounts of curvature, too, will vary, several tools of different sweeps being included in the stock of a forge, until the narrow quick forms, Figs. 15 to 17, are reached. The functions of the tools also are rather varied. The function of the fullers proper is mainly that of spreading or fullering out metal for the purpose of thinning it down, and also for the making of scarfed joints, while the function of the round-faced flatters, Fig. 14, is chiefly that of smoothing and finishing-off concave surfaces, just as the function of the flatters, Fig. 10, is that of finishing-off level surfaces. The fullers, Fig. 15, are used either in opposition to a flat face, or very frequently in opposition to a similar convex edge set in the anvil, then called a bottom fuller. Of course all these fullers are also frequently used for smoothing and finishing concave portions of work of quick curvature. Also, as the flatter in Fig. 12 is prolonged in front for finishing underneath overhanging flanged edges, so the fullers, like Figs. 15 and 17, are

FIG 14

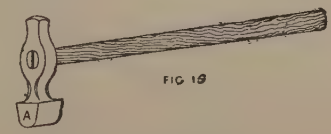


FIG 15

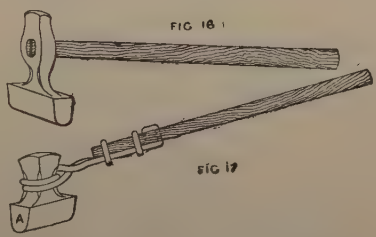


FIG 16

FIG 17

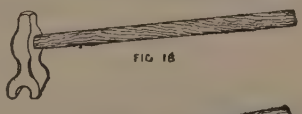


FIG 18

FIG 19

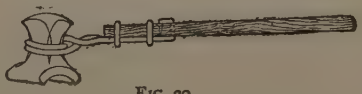


FIG. 20.

also frequently extended for 1½ in. or 2 in. at the ends A, for a similar reason. And some of the fullers are hollowed lengthwise for finishing-off convex portions of work. I need not, however, show all the various special tools of this type.

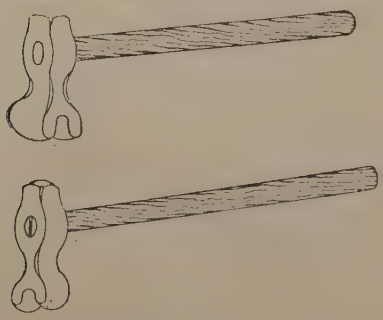


FIG. 21.

Of an exactly opposite form to the fullers are the hollow swages, Figs. 18-20. These also occur in all curvatures, from the quick, Figs. 18 and 19, to the flat, Fig. 20. Each is handled indifferently with rigid handles, and with elastic rods, and each may be curved either in the longitudinal or transverse direction, as shown in the figures. These are used for finishing and smoothing convex surfaces wherever they occur. Fig. 21 illustrates two swages, which, instead of being straight transversely to the concave portion, are curved considerably for finishing concave work.

Tongs.—The tongs used by platers and boiler-makers are rather numerous. The following are the principal types :—

The flat bit tongs, Figs. 22 and 23. These are employed for general use, for lifting about small pieces of plate and bar, both at the forge and on work in course of construction. They are made in several widths, and of different lengths of jaw. When made light, Fig. 23, they are usually distinguished as pliers. They are flat in the jaw, and enlarged behind, the enlargement permitting an enlarged portion of any object to be inclosed therein. These are used for many general purposes, as for picking up bits of work, short lengths of rod or bar, punches, drifts, and so forth, and for holding light jobs on the

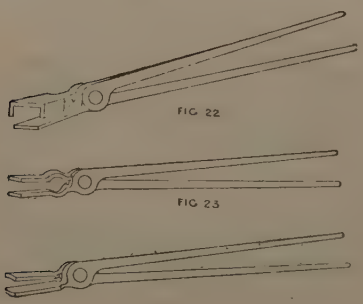


FIG. 22

FIG 23

FIG. 24.

anvil when drawing down, welding, &c. But these tongs are not suitable for manipulating long bars when they have to be turned over and round about, because the bars tend to slip sideways. One of the special forms shown is, therefore, used for long bars of square or oblong cross section. In Fig. 22 the turned-down edges confine the bar so that when the handles are grasped firmly by the hand, or in the case of long, heavy bars, confined by the ring coupler, the tongs and bar are like a single rigid piece. The tongs with hollowed jaws (Fig. 24), are employed in a similar fashion for holding round bars, and are also made in several sizes.

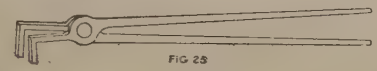


FIG 25

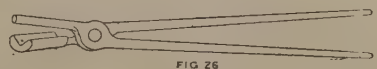


FIG 26

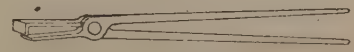


FIG. 27.

Of equal service are the hoop tongs, Fig. 25. They are employed for holding bars, rings, angles, tees, &c., at right angles with the handles. When welding up such work, and for general handling it about, these tongs are in constant service. Fig. 26 is a pair of angle-iron tongs used for grasping angle-iron at the ends, the outer faces of the angles lying in the vee of the bottom jaw. Fig. 27 is used for holding rings and bars that run transversely to the handles, the turned-down end of the upper jaw preventing slip from

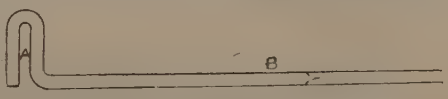


FIG 28.

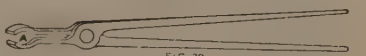


FIG 29

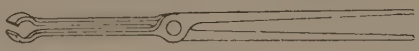
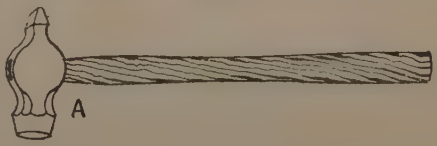


FIG. 30.



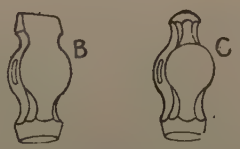


FIG. 31.

taking place. Fig. 28 is a solid lever-bar used for turning angles and tees about. The space A clips one web of the angle, and the handle B affords the necessary leverage for free movement.

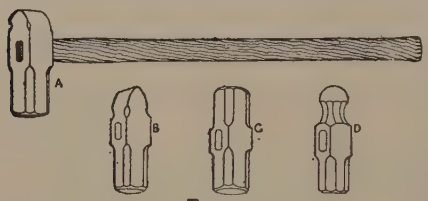


FIG. 32.

The rivet tongs, Fig. 29, are used for picking rivets out of the fire, and for inserting them into their holes. The rivets are grasped in the recessed portion A, standing therefore at right angles with the handles. Two or three pairs of such tongs, to suit smaller and larger rivets, are required. Fig. 30 shows a pair of rivet tongs specially long in the jaws. They are handy in cases where rivets have to be passed through man-holes and other openings to a man working within a boiler, or to be passed between flanges for a considerable distance before they can be inserted.

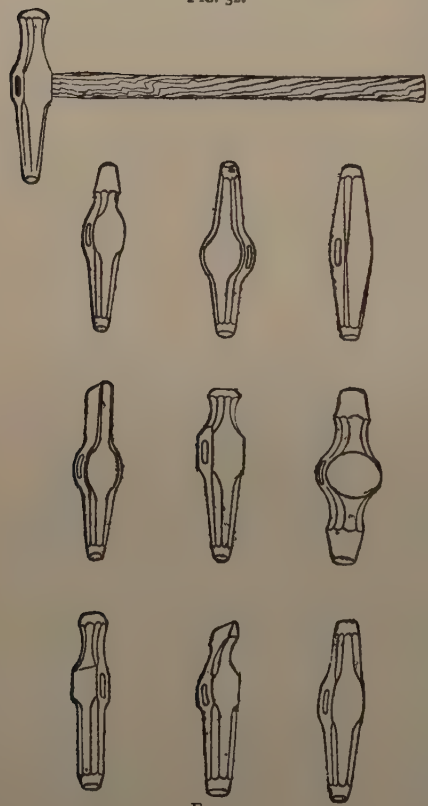


FIG. 33.

Hammers. — The hammers constitute an important section of the tools used by platers and boiler-makers — more in number than those employed in any other branch of engineering, or perhaps in any other trades except

by tinsmiths. In the first place, there are the common fitter's hammers used;—the cross pane, Fig. 31, A, the straight pane B, the ball pane C, each of two or three different weights, used on the anvil, on work in course of construction, with the chipping chisel; and for setting over and trueing up small sections of angles, and bars, and thin plates, &c. Then there are the sledge hammers, Fig. 32, in different types and of various weights;—the straight pane A, the cross pane B, the double-faced hammers C, and the ball pane D.

Of special hammers there are those shown in the group, Fig. 33. It is not possible to isolate any from the others as being restricted to very special functions; but in a general way they must be classed as riveting hammers. Each of these forms will be in ordinary use in a boiler shop; some will be suitable for the larger, some for the smaller rivets; the more slender ones will be used for the latter, and can be used in narrow spaces where the stouter ones could not be manipulated so readily. The flat ends are used for forming ordinary snap heads, the round ends for countersunk rivets. But each also fulfils an infinity of functions besides.

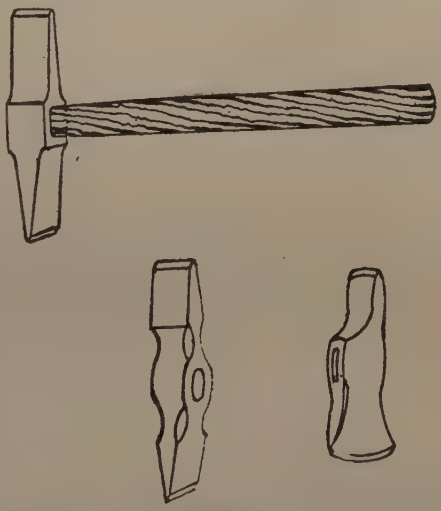


Fig. 34.

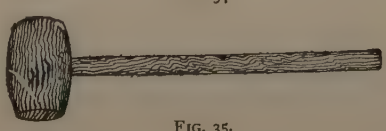
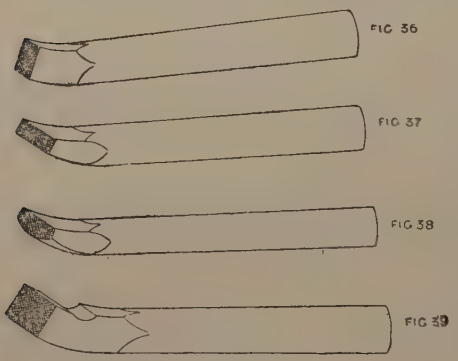


Fig. 35.

The last type embraces the scaling hammers, Fig. 34. These, as their name implies, are used for chipping the hard scale off boiler-plates, a laborious operation which has to be done in slow detail without cutting into the plate. There are only two or three modifications of this type.

Mallet.—Fig. 35 is a wooden mallet used for levelling and flanging red-hot plates when it is undesirable to use the iron hammers for fear of causing bruises. These wooden hammers are largely employed. They may be 5 in. or 6 in. in diameter by 8 in. or 9 in. long.

Caulking Tools.—The caulking tools occur in several forms and sizes. The common types are shown in Figs. 36-40.



Figs. 36 and 37 are used for the edges of plates. The only difference in them is in area, one being narrow, the other broad, the first being used for thin plates, for caulking rings, and strips, and for commencing the edges of wide plates; the second being employed for thick plates and for finishing edges, following after Fig. 36. Fig. 38 is used for caulking round rivet heads and tails. Fig. 39 is a modified

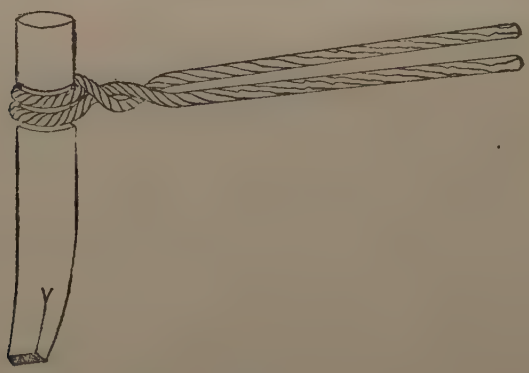


FIG. 40.

form of Figs. 36 and 37. These tools are held in the left hand and struck with a hand hammer. But for heavy caulking a

tool handled like that in Fig. 40 is used, embraced with an iron rod, or a withy stick, and struck with a light sledge. Note the serrated faces which prevent the tools from slipping, and which burr up the edges better than smooth faces could.

Rivet Sett,—and Punch.—For taking out rivets, the rivet sett, Fig. 41, and the rivet punch, Fig. 42, are employed. The

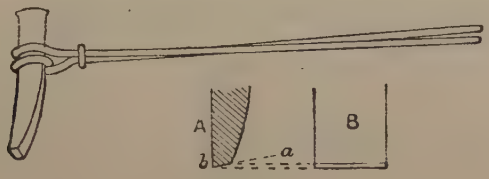


Fig. 41.

sett or chisel is ground obtusely, and being struck with a light sledge, shears off the snapped tail of the rivet. The punch is then applied, and the rivet driven out of its hole with blows from a sledge delivered upon the end of the punch. In Fig. 41, A is an enlarged section of the sett, showing the exact angle *a* of the cutting, or rather, shearing end, the cutting taking place at the face *b*. B shows the width of the tool drawn proportionately.

Drifts.—Figs. 43, 44 show drifts used for pulling plates up until their rivet holes come into line. The drift is a necessary tool, since plates could not easily be drawn into

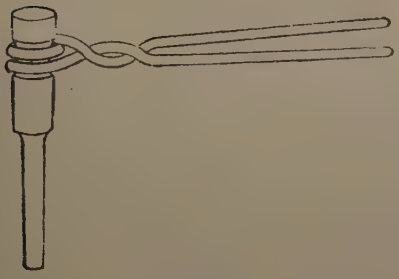


Fig. 42.

Fig. 43.

Fig. 44.

position without it. The abuse of the tool comes in when it is employed to stress and strain plates in order to pull holes incorrectly pitched into line. Observe that the drift, Fig. 43,

is bellied, so that it can be driven backwards out of its holes or right through, as most convenient. Fig. 44 is another form which cannot be driven through, but only a portion of the way into its holes.

Spanner and Podger.—Two implements are shown in Fig. 45 : A is a spanner and podger combined, B is a miniature pinch bar and podger. The tapered ends of each are used to pull the rivet holes of plates, bars, angles, &c., into line previous to the insertion of the drifts. The flattened end of B is employed to raise up the ends of plates when they are

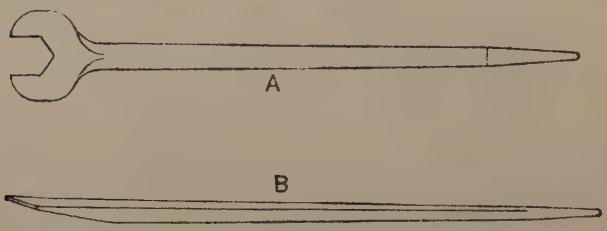


Fig. 45.

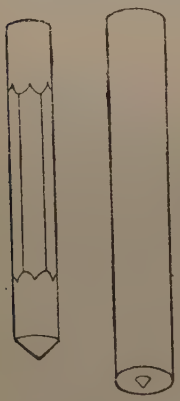


Fig. 46. Fig. 47.

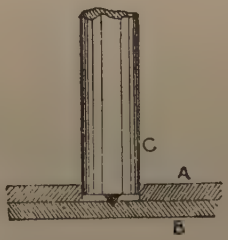


Fig. 48.

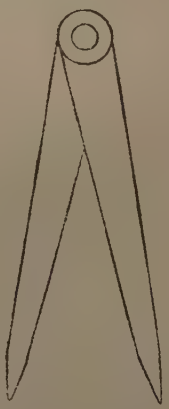


Fig. 49.

lying flat upon one another, for the insertion of hooks, chains, or the hands.

Centre Punch.—Fig. 46 is a centre punch, used for setting in deeply the centres of rivet holes before work is taken

to the punching or drilling machines. It is necessary to set in the centres rather deeply, in order that they shall become a guide to the point of the punch or the drill, the ready slipping of the tool point into the centre-popped hole much assisting the workmen when bringing the plate into position at each time of punching or drilling.

Centring Tool.—Fig. 47 is a centring tool employed to set off the centres of rivet holes from a plate which is already punched, to another which has to be punched to match. In Fig. 48, A is the punched plate, and B the plate which is being marked with the point of the centring punch, C.

Trammels, or beam compasses of the ordinary type, are used for striking curves of large radii. They differ in no wise from those employed in other branches of engineering. At least two pairs are required, one of large and one of small size, and they are made of brass, or of wood, preferably of the former.

Compasses,—Dividers.—Ordinary wing compasses and spring dividers are used by boiler-makers, and are too well-known to need illustration. But there is a special form of compass shown in Fig. 49, which is used to mark the circles of rivet holes. It is short and stout, and riveted so tightly that when set to a definite size it will remain at that radius until altered by forcible means. The tool is held in the right hand, and the circles are scribed round rapidly on the plates, angles, or bars. It is stiffer and better than ordinary wing compasses for this purpose. Fig. 50 shows a modified form of the stiff compass, used for scribing the centres of a row of rivets along from the edge of plate A. The turned round edge B of the compass is slid along the edge of A, and C marks the row of centres.

FIG. 50.

A very useful form of scribing tool is shown in Fig. 51. It also is used for scribing the centre lines of rivet holes round from the edges of plates, bars, angles, and tees. It fulfils, therefore, a similar function to the woodworker's gauge, or the

fitter's compass caliper. It comprises a piece of sheet metal, B, having its edges turned up, B′, as guides to A. One end of B is turned down, *b*, and curved to a slight radius. This face

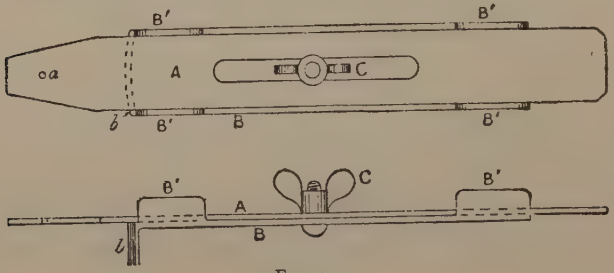


Fig. 51.

is thrust along the edge from which the centre lines have to be marked, and the top piece A being adjusted, and pinched with the wing nut C, a scriber point inserted through a small hole, *a*, marks the centre line equi-distant from the turned-down face, *b*.

Scriber.—The usual form of scriber employed by platers and boiler-makers is shown in Fig. 52. It merely consists of

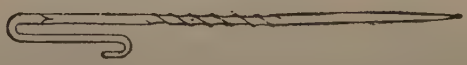


Fig. 52.

a bit of flat steel rod tapered down towards the end which is used for marking, and bent round at the other, so that it can be hung upon the edge of a piece of work when not in use.

Dividing Wheel.—A tool in very frequent use is shown in Fig. 53. It consists of a dividing wheel, A, of sheet metal, freely pivoted in bearings, C, in the handle D. It is employed for several purposes, as testing the lengths of curved arcs of section irons, testing the circumferences of rings which are being welded up, checking and marking off the centres of holes or divisions round rings and arcs, transferring dimensions from one curved face to another face either straight or similarly curved. There are a multitude of such measurements which could not possibly be taken so readily by means of rule, com-

passes, or other methods nearly so readily as by the wheel, because of the irregularity of curvature of the work, which would preclude taking circumference from diameter, or circle arc from versed sine and length of chord. Besides, it is always usual, and is much safer, in shops to check work in a graphic manner than to do so by calculations. When using the wheel, a point or points, such as *a*, become the starting points for taking or transferring dimensions. A bit of sheet tin, zinc, or brass of, say, 16 or 18 gauge, does for the wheel.

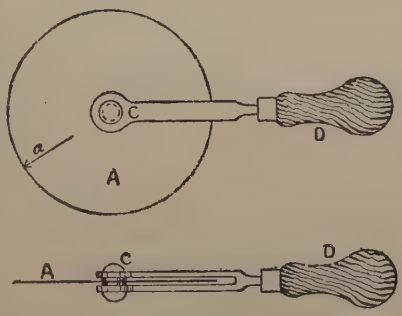


FIG. 53.

Scrape.—Fig. 54 is a tool used for scraping over rivet holes to remove the slight burr left from the punch. It is a

FIG. 54.

large file flattened at the ends, and ground smoothly like a fitter's scrape. The flattened end may be from 2 to $2\frac{1}{2}$ in. wide.

Snap.—Fig. 55 shows a snap, used for finishing or snapping the tail of a rivet. This is struck with a sledge after the

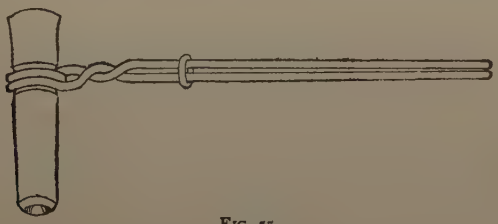
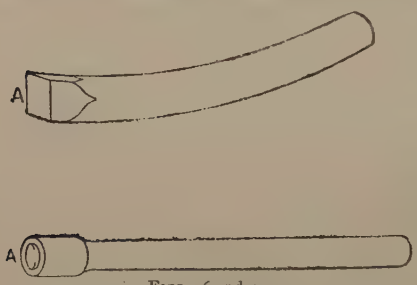


FIG. 55.

rivet-tail has been roughly turned over with one of the hammers shown in the group, Fig. 33, on a previous page.

Dollys.—Figs. 56 and 57 are dollys, used for holding against the heads of rivets while the tails are being turned over and snapped. There are other forms, but these are typical. They are made of iron rod, or bars of from $1\frac{1}{2}$ to 2 in. in diameter, and the ends A are held against the heads. One, it will be noticed, is flat ended, the other is cupped to embrace the curved rivet-head.



FIGS. 56 and 57.

Calipers.—Fig. 58 is a pair of calipers, handled like smith's calipers, with a long handle, to prevent the hand from becoming scorched when checking red-hot work on the anvil, steam hammer, or levelling block. Fig. 59 is a gap gauge, made of sheet iron. The widths of the notches are of definite dimensions, advancing by sixteenths and eighths of an inch. The gauge is, therefore, a series of fixed calipers. The widths may be stamped on the gauge, or not. This also is used for gauging widths and thicknesses of work while red-hot.

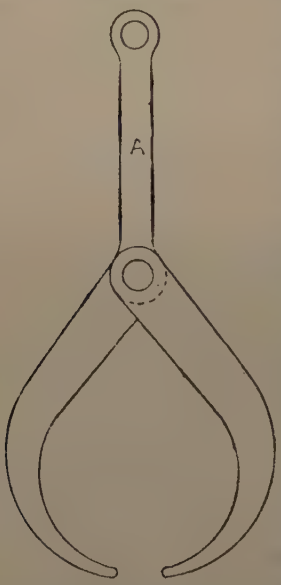


FIG. 58.

Clamp.—Fig. 60 shows a clamp made in several sizes, and used to hold plates, angles, tees, and other parts together, while holes are being marked off from one to the other.

Boiler-makers do not boast a tool-box of any kind. The small tools, as drifts, caulking tools, scribers, compasses, and so forth, are carried about in small open tin trays of 10 in. or 12 in. square. The larger tools, the hammer, tongs, &c., just lie about in the vicinity of the work, and are kept in racks beside the forge when not in use.

Drills.—A good deal of drilling, countersinking, rymering, and sometimes cutting of screw threads has to be done by

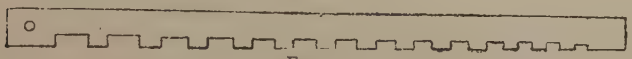


Fig. 59.

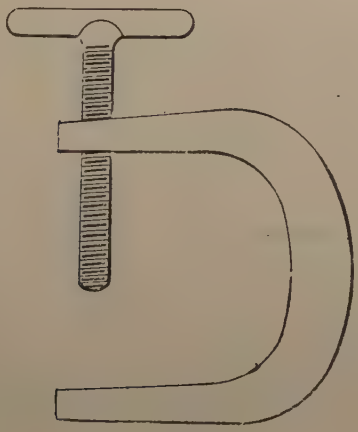


Fig. 60.

platers and boiler-makers. The tools used are those employed in the machine shops, and need not be illustrated. The drills used are of the flat double bevelled type, or else of the twist form. Rymers are half round, broaches are solid with grooves, countersinks are either double bevelled, or with rose ends.

CHAPTER III.

MATERIALS.

Iron and Steel.—Diversity in Quality.—Sectional Forms.—Wrought-Iron.—Method of its Production.—Stages of Puddling.—Piling.—Want of Homogeneity.—Mild Steels.—Method of their Production.—Open-Hearth.—Bessemer.—Comparison between Iron and Steel.—Lamination.—Blisters.—Strength as shown by Test-Pieces.—Ductility.—Direction of Fibre or "Grain."—Limiting Sizes.—Relation of Strength to Ductility.—Copper.—Impurities in Ore.—Strength as Affected by Temperature.—Its Employment by Boiler-makers.—How Worked.

Materials — Iron and Steel. — There are only two materials used in plated work, and three in steam boilers, namely, iron, steel, and copper. The physical qualities and characteristics of these materials, especially of the first two, vary so much that the utmost precautions are necessary in making selections of them for given purposes, as is evidenced by the elaborate specifications, minute inspection, and exact tests by which contractors are bound. And there are few branches of engineers' work to which so much patient study has been devoted, and which is so full of varied interest, as the behaviour of these materials under stress and strain, and the alterations which they undergo under modified conditions.

Diversity in Quality.—Plates and section-irons shall be brought into a shop, having the same general external appearance, but in actual fact they shall be as diverse in character as though they were of quite different materials. And the differences in their physical characteristics are so many and varied that, speaking in general terms, the best materials are those in which a balancing and blending of several diverse characteristics occurs. I propose, therefore, in the course of a few pages, to explain and illustrate the special characteristics of these materials, the conditions which govern their selection for given purposes,

the methods of testing, the effects of temperature, and of work done upon them. These are all matters of cardinal importance, to which increasing attention is being devoted year by year.

Sectional Forms.—Iron and steel are used in the plating and boiler shops in the form of plates, bars, rods, rivet iron, and rivets, and in various irregular sections, the principal of which are angles, tees, channels, and H sections.

Wrought-Iron.—Wrought-iron has been, until very recently, by far the most important material employed by the plater and boiler-maker. To a very large extent it is being superseded by the mild steels. But until quite recently there were few experienced boiler-makers who would not have expressed an opinion more favourable, on the whole, to iron than to steel. They felt safer, more at home, more confident when working iron than they did when working steel. Wrought-iron was more workable, less liable to crack, would stand greater extremes of heating and cooling, would endure more flanging, hammering, and punching without injury, was more weldable, and required less annealing than steel. Yet tests show conclusively that good steel is a better material than iron. With increasing knowledge of the value and properties of the various steels, and more extended practical experience, the difficulties attendant on the working of steels are being diminished, and will ultimately disappear. The reason of this is that the steel first introduced was too much like temper-steel and too little like wrought-iron to be suitable for the purposes for which wrought-iron had been used. High tensile strength was sought at a sacrifice of ductility, and hence many practical men too hastily concluded that the new material was not so workable or reliable as wrought-iron. Methods of working adapted to wrought-iron were found to fail when applied to steel. But with the introduction of a milder material, and experience gained in its working, the objections to its use have mainly disappeared.

Before taking up the consideration of the differences in the relative workability and respective values of iron and steel for various classes of work, it seems necessary that we should have a clear idea of the essential differences in the methods of manufacture of iron and steel.

Method of Production.—Wrought-iron differs from steel in many ways, both chemically and physically; but the chief difference consists in this: that wrought-iron has not been

fused, while steel has been. And there is, consequently, a lack of that homogeneity in wrought-iron which is possessed by steel. Another difference is, that wrought-iron is produced in contact with fettling materials, some portions of which, getting intermixed with the metal, are sometimes permanently entangled with it, and are not expelled in the subsequent processes of hammering, squeezing, and rolling; and these cause laminations and blisters—evils which do not occur in the pure bath of molten steel.

Very briefly, the details of the production of wrought-iron are as follows:—White pigs of cast-iron are heated in a reverberatory furnace of special construction, for the more or less complete oxidation of the foreign elements always present in pig, and which would constitute impurities in wrought-iron. These elements are silicon, carbon, phosphorus, sulphur, and manganese. In the earlier process of making wrought-iron the elimination of these elements was effected mainly by the oxygen of the air; but in all modern puddling processes the air plays a very minor part, the essential agents of oxidation consisting of basic linings and oxidising fluxes introduced into the reverberatory furnace. The bottom of a puddling furnace is prepared for its charge by introducing a layer of tap cinder, broken slags, hammer scales, and old broken-up hearth bottoms —substances rich in oxide of iron. These are fused and spread over the bottom. A fettling called "puddlers' mine," being red hæmatite, a nearly pure oxide of iron, is spread over this. The sides are also fettled with roasted tap-cinder (bull-dog) and with puddlers' mine.

Stages of Puddling.—Speaking in general terms, the operation of puddling is completed in four stages, corresponding in the main with certain well-marked chemical reactions, but subject to modifications according to the nature of the pig used in the process.

During the first stage the pig is melted down, and the silicon is partly oxidised out. This will occupy nearly half an hour, and any graphitic carbon present is brought into the combined condition.

During the second stage the chimney-damper is lowered, and the temperature reduced, and the metal is drawn from the sides of the furnace towards the centre, where there is greatest fusion, and thoroughly mixed with the cinder and fluxes. This lasts about seven minutes.

At the third stage the damper is raised, and the temperature increased. Violent ebullition ensues, due to the escape of carbonic acid gas, which burns with a blue flame ("puddlers' candles"), and the oxidation of the phosphorus, sulphur, and manganese; and these violent oxidations are assisted by the action of the puddler, who rabbles the metal vigorously about on the hearth, thus exposing fresh surfaces to the action of the basic materials and to the oxygen of the air. This stage lasts about twenty minutes or thereabouts, at the close of which the metal "drops" or "comes to nature," ebullition having ceased.

Finally, in the last stage the metal is broken or balled up into lumps of convenient size, 60lb. to 80lb. weight each, for removal from the furnace. It is now in a pasty condition, and the balls are rolled to the fire bridge of the furnace, and allowed to remain there a few minutes to take a suitable welding heat previous to withdrawal. The balls are taken out with tongs through the working door, and run away on a bogie to be shingled under hammer or squeezer. During the process of shingling a large quantity of slag and cinder is squeezed out from the ball.

The puddled ball is passed from the squeezers or hammers to the puddle-rolls or forge train, and there rolled into slabs, or puddled bars, varying in size according to the purposes for which they are destined. The bars range from 7 in. to 15 in. in width, if intended for plates; but are narrower, from 3 in. to 7 in. in width, if intended for bars only. They will range from $\frac{3}{4}$ in. to $1\frac{1}{2}$ in. in thickness. This is the first stage in the manufacture of the crude, or No. 1 iron.

It is obvious that although much more pure in the matter of chemical composition than cast-iron, it is mechanically non-homogeneous, containing slag and cinder, entangled and intermixed with its mass, and which have not been expelled during the shingling process. This is an evil inseparable from all wrought-iron, even the best plates and bars sometimes containing portions of slag, cinder, and scale, hidden away in their substance. And leaving out of the question some special and costly brands, the essential difference between the common and the best brands of iron is due to the subsequent work done upon the puddle bars in the rolling mill.

Piling.—Briefly, the treatment is as follows:—The puddle bars are cropped or cut off with shears into convenient

lengths, and piled. A pile is not made at random, but in such a way that the bars comprising it shall cross and break joint, and produce an interlacing of fibre. Piles vary in size and weight. A common weight is about 4 cwt., the section being 8 in. or 10 in. square, and the length from 30 in. to 40 in. The whole is bound together with hoop-iron. In piling for plates, the central portion is formed of crossing bars, but the top and bottom are formed of solid slabs of about 1½ in. thickness. Moreover, the interior of a pile is not necessarily wholly formed of puddle bar, but crop ends, old scrap, bolts, spikes, properly cleaned from rust in a rattle barrel, are also placed in the centre. This is especially done in large railway and other firms that roll their own plates or bars. The pile, properly bound together, is then introduced into the reheating or balling furnace. This is a reverberatory furnace, in outline much like the puddling furnace, but having a smaller proportional grate area, and it is lined with sand on a brick bottom, in place of fettling, and the general outlines differ also according to the nature of the charges for which it is designed. The pile is raised to a welding heat, and hammered to consolidate the mass, and then rolled into a plate. The rolling is done between two sets of rolls, one roughing, the other finishing.

Since the extension of the plate takes place almost entirely in the direction of its length, it is first extended to a length which is the actual width of the plate. It is then turned round at right angles, and rolled in that direction until it approaches the required length and thickness, at which stage it is transferred to the finishing rolls. Finally, the ends are cut neatly with the shears.

Only the commonest plates, however, are produced from bars once piled and reheated. The crossing and piling of the bars is repeated for better qualities of iron, and, of course, as this involves increased outlay for fuel and labour, that is the reason why plates of superior quality cost so much more than inferior plates. But more than this, in the case of some special brands, such as Lowmoor and Bowling iron, great care is exercised in sampling the products of a given "heat," and making selection and division according to the quality of the fracture. But in other respects as well the working of the Yorkshire furnaces is exceptionally costly. The crude iron is in the first place produced from cold blast pig. The pig is

usually refined before its introduction to the puddling furnace. The charges are small, and the consumption of fuel large, as much as about 30 cwt. per ton of metal. The ore is of a special character, and the fuel is relatively free from sulphur and pyrites. Thus everything conduces to a product of exceptional purity. After the puddled balls are produced, they are shingled into blooms of about 10 in. or 12 in. square, and of from $1\frac{1}{2}$ in. to $2\frac{1}{2}$ in. in thickness, and these are broken up into small portions and sampled carefully, according to fracture. The harder and more crystalline portions are used for bars, while the softer and more fibrous are used for boiler-plates, &c.; being then piled, reheated, and welded into blooms, which, being again reheated, are passed between the rolls for the production of finished bars, plates, &c.

Want of Homogeneity.—It will now be clear why some imperfection, more or less, is inseparable from the manufacture of all wrought-iron. Some amount of cinder and fused slag becomes intermixed with the puddled ball, and remains embedded in the iron of the pile, notwithstanding that by far the major portion is expelled during shingling and reheating. These particles become spread out and elongated during the process of rolling, and form the laminations so well known to the boiler-maker, and which are so difficult of detection in the interior of plates. Cavities also result from the occlusion of gases, while on the outside of the plates similar causes will result in pitting, or the formation of small shallow depressions on the surface.

Mild Steels.—The manufacture of the mild steels has scarcely any points of resemblance to that of wrought-iron. It is true that pig-iron is the basis of the product in each case, and that it is in each case fused, and its foreign elements oxidised in a reverberatory furnace; but here the analogy ceases. For while wrought-iron lies on the bed of its furnace in a pasty condition, and can be rolled and lifted about in the form of spongy balls, steel is in a perfect state of fusion, and is poured into ingot moulds. Hence the great difference in the resulting homogeneity of the finished iron and steel, as we shall see in a practical way later on. In the meanwhile, I will describe briefly the methods of manufacture of the mild steels, as I have done in reference to that of iron, since many of my readers will certainly not have had the opportunity of observing either process.

Method of Production.—Omitting many minor details and slight modifications in practice, the methods for the production of mild steel—meaning by that steel so low in carbon that it will not temper, in this respect resembling wrought-iron—embrace the open-hearth, and the Bessemer processes. The latter, though the first in the field in point of time, is being rapidly distanced by the former. The former includes broadly four distinct methods—the Siemens, the Siemens-Martin, a combination of the two, and a basic open-hearth process. It is not necessary to describe these severally and in detail, since there are cardinal methods common to all.

Open-Hearth Methods.—In the various open-hearth methods the materials used are certain hæmatite pig-irons, melted on the hearth of a reverberatory furnace of a quite special construction. As a matter of economy, though not of necessity, scrap steel, consisting of crop ends, old rails, bars, and shearings, are added to the iron. The whole is brought to a state of fusion. The molten bath of metal is then decarbonised by the addition thereto at intervals of hæmatite iron ore, the result being a violent ebullition of the metal, due to the disengagement and escape of the products of the oxidation of the foreign elements—the carbon, silicon, and manganese. The bath is then recarbonised by the addition of spiegeleisen, or more generally of ferro-manganese—alloys of iron which contain a large proportion of carbon. The reason why hæmatite pig-irons are used is because they contain small percentages only of sulphur and phosphorus, elements which are not capable of oxidation in the ordinary process. But if the furnace is lined with basic materials—that is, materials rich in metallic oxide—then ores having larger percentages of sulphur and phosphorus can be used, and these deleterious elements eliminated.

Bricks of magnesite and of bauxite, or a mixture of calcined dolomite and anhydrous coal-tar, are used as basic linings. During the period of decarbonisation, buttons of metal are tested from time to time, both by fracture test, and by rough chemical analysis. This is one of the great advantages possessed by the open-hearth processes over the Bessemer—that the steel can be dead-melted, and the temperature regulated so that the bath of metal can be allowed to remain quiet and unaltered for a very considerable period, while tests are being made previous to the addition of the spiegel or ferro. After

the recarbonising agent is added, however, the metal must be rabbled at once, and rapidly, and tapped quickly, otherwise too much manganese will be lost in the slag, and the metal will become red short.

Bessemer Process.—In the Bessemer converter also pig-iron is decarbonised, and recarbonised. But here the atmospheric air blown through the molten metal is the decarbonising agent, and the process is therefore a brief one by comparison with that accomplished in the open-hearth furnaces, and consequently the composition of the resulting product is not so readily under control.

The succession of operations which are performed in the making of steel in the Bessemer converter is pretty well known; how the converter is heated, turned down, the melted pig emptied in, the blast put on, and the converter turned up in order that the blast of air shall oxidise the foreign elements in the pig; and how, when the oxidation is complete, as evidenced by the dropping of the flame, the converter is once more turned down, and spiegel or ferro added for recarbonisation—it is not necessary to dwell on this in detail. The result is very similar to that obtained in the open-hearth furnaces; but the chemical composition of the steel is not so fully under control, and Bessemer steel, therefore, is mostly used for rails and tyres, and not so much for plates and bars, in which ductility is of greater importance than hardness.

The distinctions between acid and basic Bessemer steel do not concern us either. The point of interest for us is that, in whatever way mild steel is made, it is poured into an ingot mould in a *perfectly fluid condition*, and is, therefore, a homogeneous product as far as freedom from scale and from slag is concerned. There is a certain unsoundness in steel ingots, but this is due to the occlusion of gases in cavities, or to the formation of cavities about the head of the ingot, and, due precaution being taken, it seldom enters into the finished bars and plates. The ingots are stripped and reheated in suitable furnaces of various types, or the heat due to melting is diffused equably through the mass of the ingots in soaking pits, and the ingots are rolled into blooms in the cogging mill, and reheated for final rolling; or in many cases the finished product is rolled at once.

Comparison between Iron and Steel.—We are now better able to appreciate somewhat the fundamental reason of

the differences in the physical conditions of finished iron and steel plates, bars, &c.

It is not a question of chemical composition so much as of modes of manufacture. There is so little difference in the chemical composition of wrought-iron and some of the mild steels, that it is impossible to draw a hard-and-fast line between them; they merge into one another by imperceptible degrees. The only distinction that can be made is that due to methods of manufacture and physical condition. Hence mild steel is commonly termed *ingot iron*—a material which has been cast and is malleable; and the malleable or wrought-iron is termed *weld iron*—a material which, though malleable and weldable, has not been cast. Because it has not been fluid, the evils inseparable from its crude, spongy condition when in contact with the fettling of the furnace cling to it more or less through all its career. Because steel has been fluid, its impurities have been removed in the head of the ingot. In subsequent pages we shall note how these fundamental distinctions receive practical illustration in the workshop.

We are now in a position to understand the reason of the cardinal differences that exist between wrought-iron and mild steel, and also to observe their practical effects in the workshop and under test, and likewise their bearing on the design of structures. The subject is one of great interest and fascination, not only to the engineer, but also to the student and general reader.

Lamination and Blisters.—Many years since Dr Siemens termed wrought-iron a "sandwich of iron and dirt," and, with all due allowance for prejudice in the mind of the inventor of open-hearth steel, we must admit the substantial truth of his definition. No one can ever be sure that, out of a batch of plates brought into the shop, some will not be faulty by reason of the presence of lamination and blister in the interior, due to the presence of slag and scale in the original bloom or pile. The outsides of plates will generally be fair enough, and probably an examination of the edges will show no defects. But there may be, and often are, these imperfect welds in the interior of the plates, which the utmost care will fail to detect, but which will ultimately result in extensive corrosion, and perhaps fracture. These evils are never totally eliminated from the best plates of the best houses, and they are relatively common in inferior and cheap material. The

thicker the plate the more likely it is to be faulty. Frequently these laminations and blisters are only discovered during working, during heating, bending, and flanging, or even after the work is done. These evils are of serious account in steam boilers, especially when they occur in plates exposed to the action of the flame, or to the alternate action of flame and of currents of cold air, which produce sudden expansion and contraction of the plates.

It is customary to test all plates specially for defects of this kind, both by ocular observation, and by the hammer, before working them up. The faces and edges are examined, and the surface is tapped all over with a hand hammer in order to judge of the existence of hidden flaws by the sound, the presence of laminated parts being indicated by a dull sound instead of the sharp metallic ring which is characteristic of a perfectly sound plate. The plate under test is either supported vertically on edge, or it is supported horizontally at the four corners, and fine sand strewn over the surface. If tapped then on the under face, the sand will remain comparatively undisturbed over the areas in which lamination may be present. Also when plates are heated, laminated or blistered portions will, if visible, look black by comparison with the sound portion. Spite of all precautions, however, these defects will frequently remain undetected. On no account, however, should a plate known to be laminated or blistered be worked up into a boiler or other structure subjected to great stress. It should be returned to the maker, or the defective portions should be cut out if the nature of the work will permit of this, or the plate should be cut up for smaller jobs. Owing to the presence of imperfect welding, which often occurs undetected in the heart of the best wrought-iron, structures made of that material are liable to secret corrosion, due to water making its way inwards. This would remain quite undetected, while acting injuriously on the strength of the iron. It is an evil which cannot well occur in the case of homogeneous steel, the only corrosion to which steel can be subjected occurring at the surface, where protective methods can be adopted. Steel plates are almost free from these laminations. They so seldom occur that they may be regarded as practically non-existent, and this is one very great point in favour of steel considered as a material for plating and boiler-making.

Strength as shown by Test-Pieces.—There is further,

as might be expected, much greater uniformity in the strength and other physical characteristics of steel of a given delivery than there is in a delivery of iron plates. Prof. Kennedy's experience, derived from exact tests, gives a variation of about 4 per cent. on each side of the specified results in the case of steel, while in wrought-iron there would be nearly double that variation. Again in specimens cut anywhere from a single plate of steel, results are substantially the same. But very considerable variations in strength will be found to exist in specimens cut from the same plate of iron. In fact, Prof. Kennedy once gave it as his opinion that the use of small test-pieces failed to denote the real strength of the plate from which they were cut, because of the defects due to imperfect welding of the layers, and he suggested the use of strips cut off the whole length of the plate. The Iron and Steel Committee, in 1868-70, also made experiments with bars of iron and steel of 10 ft. in length, and the tests were more uniform for the same material than is the case when short pieces are used. At the present day test strips cut anywhere from a steel plate give substantially the same results. And not only so, but strips cut from any one of the same batch of plates would show very little difference, not more than a ton or thereabouts in strength. This, however, cannot be said of the best iron.

Ductility.—The next point to be noted is that iron has only about half the ductility of mild steel. Speaking generally, an iron of good quality will have a tensile strength of about 21 tons with the grain, and 18 tons across the grain, and an elongation before fracture of about 10 per cent. in eight inches; so that it will not stretch quite an inch in that length before breaking. Mild steel will not only have a strength of from 26 to 30 tons in both directions, but will elongate 20 per cent. in eight or ten inches before fracture. The difference in the ductility of iron and steel, amounting to 100 per cent., is a very important difference, not only as affecting reliability under stress, but also as affecting the working of the two materials at the forge. We should naturally expect steel to stand bending, flanging, punching, and so forth better than iron, and, with certain precautions, we should find that it would do so. But it is necessary to observe these precautions, for if we do not, then steel is a worse material in the hands of the boiler-maker than iron. And the difference is mainly due to the fact that iron is fibrous, and steel is crystalline. If you slowly and

naturally stress a piece of good iron to rupture, whether by bending or stretching, the fractured ends will be fibrous, but in steel similarly broken the ends will be crystalline. In some specimens, however, of very mild steel, slowly broken, the fracture will be partly granular and partly "silky." Still, the distinction just named of fibrous and crystalline is a cardinal distinction always present to a greater or less extent.

Direction of Fibre, or "Grain."—The difference in direction of fibre, or "grain," as it is called, in wrought-iron has always to be considered in working. A plate or bar subject to direct tensile stress has to be placed in such a position that the longitudinal direction of the fibre shall correspond with the direction of greatest tensile stress. Also, when flanging and bending plates, the work should always, when practicable, be done in the direction of the grain. But this is not always practicable, as, for instance, when flanging a circular plate, where on two sides there must needs be short grain. And in such cases the difficulty and danger of flanging without cracking comes in, and a good deal of careful heating and gradual working have to be done in order to produce a sound job. It is difficult to bend to a quick radius across the grain in good plates; it is impossible to do so at all in plates of inferior quality. With steel, on the other hand, there is so very little difference in the strength taken in the direction of rolling, or at right angles therewith, as to be practically negligible, and flanging and bending can be done indifferently in any direction. The same remark applies also to the directions in which tensile stresses occur. Steel may be stressed equally in all directions, whereas wrought-iron will endure three or four tons more of stress in the direction of the grain than across it. Tests show, however, that slight differences in *ductility* occur in steel, with, and across, the grain. In a memoranda on Experiments on Mild Steel issued in 1885 by the Board of Trade, for the use of their surveyors, it was clearly proved that although the ultimate stresses in mild steel are as nearly as possible equal lengthways and crossways, yet the *ductility* as measured by extensions and contractions of area was greater lengthways than crossways. The mean of a series of experiments undertaken gave for ultimate extension in 10 in.: lengthways, 27.6 per cent., and crossways, 25.3 per cent.; for contraction of area at fracture: lengthways, 50.7 per cent., and crossways, 48.6 per cent. In the same memoranda it was mentioned by way of contrast,

that the mean of a number of ordinary iron boiler plates gave a contraction of area at fracture lengthways and crossways of only 13.07 and 4.41 per cent. respectively; and that the contraction of area at fracture of some ship plates lengthways was only 5.4 per cent.! (*See* p. 47.) The importance of a high degree of ductility can scarcely be overrated, because of its value in giving timely warning of approaching rupture by the leaking at rivet holes due to elongation.

Limiting Sizes.—The limiting sizes of plates are less in iron than in steel, and this is a very important matter in many cases where it is desirable to avoid as much as possible the cost, and reduction of strength due to riveted joints. The limiting weight of ordinary wrought-iron plates is usually from 4 cwt. to 6 cwt., an amount which is exceeded in only a few localities. The reason is, the difficulty and cost of shingling and piling large masses with sound results. But the only limit to the size of a steel plate is the limit imposed by the capacity of the cogging and rolling machinery employed in the production of the finished sections. Steel ingots are commonly cast of from 15 cwt. to 25 cwt., and even 50 cwt. each. Of course this is a very general way of putting it. Thin plates of large area cost more than thicker plates of smaller area, even though of the same weight. And some houses having the advantage of heavy plant are able to roll heavier sections than others without an increase in cost. Particulars of these sizes are given in Ryland's "Directory of the Iron Trades," for many houses in the kingdom. The same remarks apply generally to other sections besides plates. Channels, angles, tees, bars, and rods can all be made correspondingly heavier in section and in length combined than in iron, and this also is of great practical convenience sometimes, both in point of strength and in lessening the numbers of end joints.

Relation of Strength to Ductility.—Much of the bad repute which steel has suffered, both in the opinion of engineers and of boiler-makers, has been due to a lack of appreciation of the qualities necessary for certain purposes. When mild steel was first introduced, the advantage which it possessed of superior strength with reduction of weight over wrought-iron chiefly occupied the attention. Consequently in the early days of steel-making, carbon steels of an ultimate strength of from 35 to 40 tons were used for purposes to which they should never have been applied, and as these steels have but a low

ductility, the result was cracking and sudden fracture where there should have been ductility and elongation. Gradually engineers have learned by failure that some considerable *tensile strength must be sacrificed to ductility*, and so the steel plates of to-day are made with a strength only about a fourth more than that of wrought-iron, but with a ductility about twice as great; and this is the ideal material for boilers and other structures subject to great and sudden stresses. Recognising, too, that there is little in common with extreme varieties of steel except the name (hence the substitution of the term ingot iron), the several materials used for various purposes are marked by special characteristics—as extreme hardness and tensile strength, as for rails; or great elasticity, as for boilers and rivets; or a mean between the two, as for ship and girder work. And for each of the classes or grades of steel, as for iron, there are special tests commonly made use of by which the special qualities of the different grades are better demonstrated than by any other tests. These matters are so important in their practical bearings that I will treat them in some detail in the next chapter.

Copper—Impurities in Ore.—Copper is extracted from its ores by a series of costly and prolonged processes which are rendered necessary by the presence of a large number of foreign elements, each of which, if present in only very minute quantities in the commercial product, are extremely detrimental to its strength and ductility. Different processes have to be adopted with the different ores, which ores occur chiefly as oxides, mixed with sulphides. The principal foreign elements generally present are iron, sulphur, antimony, and arsenic. The coal used in the successive calcinations, smeltings, and roastings may amount to as much as eighteen times the weight of metallic copper extracted. The metal resulting from this series of processes is often more or less impure.

Strength as Affected by Temperature.—Copper is also very susceptible to ill treatment in working, especially so to overheating (*see* Table I. p. 39), which causes it to lose its ductility, and become granular and brittle. At 580° Fahr. it loses about 25 per cent. of its normal strength. The bursting of the steam pipe on board the "Elbe" in 1887 occurred at a pressure of less than one half that which it had borne by cold water test. That this was due to overheating at the brazed seam was also borne out by the testing of strips of the metal.

Strips cut from the metal in its normal condition showed a tenacity of 33,000 lbs. per square inch, with an elongation of 33 per cent. in 5 in., while strips cut from near the brazed seam showed a tenacity of 24,418 lbs. only, and an elongation of but 4.6 per cent. Since then the Elmore electryolitic copper-depositing process has given us seamless copper pipes of the largest size required.

Its Employment by Boiler-makers. — Copper is chiefly used by boiler-makers for fire-box sheets and plates. We, in England, do not use steel to so great an extent for tube plates and sheets as is the practice in America, and on some of the Continental railways. Steel has been tried in England, but is not considered so satisfactory as copper. Copper has only about one half the tensile strength of steel, or from 12 to 14 tons per square inch, and, as we have seen, this strength is much impaired at high temperatures. But, on the other hand, it possesses these advantages:—Its heat conducting power is greater, and not only so, but it does not become covered with scale so readily as steel, and therefore since scale is a bad conductor of heat, the advantage in conductivity on the side of copper is twofold. It is also more ductile, and will stand flanging well, and is better able to accommodate itself to sudden and great changes in temperature.

How Worked.—Copper can be worked either hot or cold. Hammering it makes it brittle, but annealing restores its tenacity. Thin sheets, and even thick sheets, if of good quality, can be worked cold. For flanging to quick curves, all but the thinnest sheets are heated to a blood red, a temperature which on no account must be exceeded, otherwise the copper will crumble and break under the hammer. A test of good quality in copper is to bend it quite double without sign of cracking.

Good copper when fractured should have a fibrous silky appearance, inferior copper has a coarse and blackened face; the latter will be red short, and break easily. If copper is overheated, but allowed to cool down before any work is done upon it, it regains nearly or quite all its original strength, but on no account should work be done upon it while overheated. It is for this reason that so much diversity occurs in the recorded strength of structures made in this material, although the purity or otherwise of the metal exercises a variable influence. Some alloying elements, however, do not

exercise a deleterious influence, but the reverse. Mr Stroudley preferred copper having a slight admixture of tin for the fire-boxes of his locomotives, believing that they suffered less from the cutting influences of the blast and fuel than pure copper. For steam pipes, the purer the copper the better. This is secured by the Elmore process. Over the purity of the material in which he works the boiler-maker can exercise no control, so that his special care must be directed to the due regulation of the temperature required during the bending or flanging of his work.

The following table shows the diminution of strength which copper suffers with increasing temperatures :—

Table I.

Experiments made at the Franklin Institute, America, in connection with an Investigation into the Strength of Boilers.

Temperature above 32 Deg.	Diminution of Strength.	Temperature above 32 Deg.	Diminution of Strength.
Deg.		Deg.	
90	0.0175	660	0.3425
180	0.0540	769	0.4389
270	0.0926	812	0.4944
360	0.1513	880	0.5581
450	0.2046	984	0.6691
460	0.2133	1000	0.6741
513	0.2446	1200	0.8861
529	0.2558	1300	1.0000

CHAPTER IV.

TESTING MATERIALS.

The Tensile Test.—Maximum and Minimum Strength.—Breaking Strength, and Elongation before Fracture.—The Elastic Limit.—Stress-Strain Diagram.—Standard Test-Pieces.—Iron Plates.—Various Qualities.—Tensile Tests.—Forge Tests.—Nicking Test for Fibre.—Section Irons.—Forge Tests—Hot and Cold.—Mild Steel—Various Qualities.—Tensile Tests.—Forge Tests—Hot and Cold.

The Tensile Test.—There is only one test employed in practice for wrought-iron and steel—the tensile—of which bending is but a modification. The compressive test is of relatively little value in practice. We will first consider the purely tensile, and then the commercial tests.

Minimum and Maximum Strength.—In the case of iron, a maximum strength and not a minimum strength is required; but in the case of steel, all official requirements agree in limiting the *maximum* as well as the minimum strength—that is, the specimens tested must not exceed a certain tensile strength. This specified strength varies somewhat, as will be noted presently; but it may be roughly taken as ranging from 26 to 30 tons per square inch. And of equal importance is the stipulation that it shall have an elongation before fracture of 20 per cent. in a length of 8 in., or, in some cases, 10 in. This means that the specimen tested shall be stretched to about 2 in. in 8 in., or 10 in., before it fractures—a splendid illustration of the ductility possessed by mild steel. The test-pieces are small portions of definite length and section cut from plates, bars, or forms of other materials, and subjected to stresses of various kinds, their behaviour under stress and strain affording an indication of the physical characteristics of the materials from which they were cut. There are many methods of testing—some of a rough and approximate character only others of a highly scientific character, made with the greatest precision,

the former taking note chiefly of the force necessary to break a test-piece, together with its amount of ductility as evidenced by percentage drawing out or elongation previous to fracture; the latter observing the minute and local increments of extension corresponding with definite stresses. It is with the former methods we are chiefly concerned in dealing with the subject from the point of view of the workshop; but it is also desirable that we should have some clear ideas of the relation of those methods to the higher scientific methods of testing. These relations, and the precise meaning of certain terms employed in the testing of materials, I will now proceed to explain.

Breaking Strength, and Elongation before Fracture.—Taking any ordinary test-piece, Fig. 61, No. 1, which

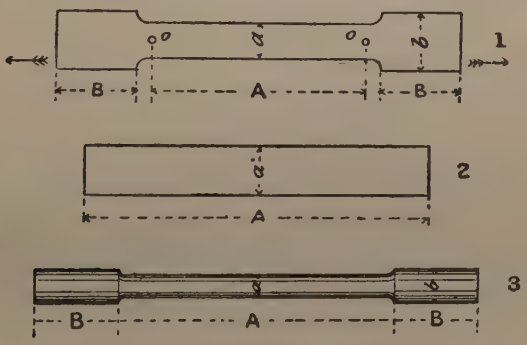


FIG. 61.

is pulled asunder in a testing machine, there is a certain length, A, of definite cross-section, on which the results of testing are observed. The portions B B beyond A are of no account whatever, being simply made of convenient size to be gripped by the shackles of the machine. A gradually increasing load is applied to the specimen, pulling it in the direction of the arrows until the rupture of the test-piece results, and this final load is called the *breaking load*, or *ultimate load*, and its measurement in tons or pounds is called the ultimate or the *breaking strength* of the material, and this breaking strength is usually the most cardinal matter placed on record in estimating the value of a material for a given purpose. But even in rough testing there is the other matter of quite equal value,—namely, the amount of stretching which the specimen

undergoes before the ultimate load is reached. This is called the *elongation before fracture*, and is evidence of ductility or capacity for being drawn out, and is given in percentage terms of the length A of the test-piece. Thus, if the length A originally equals 10 in., and is elongated 2 in. at the moment of fracture, then there is an elongation of 20 per cent. In specifications, and in commercial tests, these are the two points noted in estimating the combined ultimate tensile strength and ductility of a material.

The method, then, of estimating the ductility of the material used in test-pieces usually is to measure the length or extension between the gauge points, *o*, *o*,—8 in. or 10 in., in plate specimens,—after fracture, and this is more reliable than measuring the *contraction of area* at the point of fracture, though this also is sometimes taken. Still, the latter is thought to be affected by non-homogeneity at the point of fracture, an objection to which the former, extending over a greater length, is less open. Yet in the former case by far the largest part of the extension is due to *local* extension, which is influenced by local physical conditions. For this reason it is desirable, in cases where exact tests are wanted, to observe certain precautions, such as measuring the extension up to the limit of elasticity, taking two or three test-pieces from a single plate or bar, measuring the extension before the local contraction begins, or measuring the broken piece without taking account of the length affected by local contraction.

The Elastic Limit.—But, after all, these are crude tests taken alone, because they tell little or nothing about the *elasticity* of the material under test, or about the capacity which it may possess of returning to its original condition after the imposition and removal of working loads, and in most cases this is a question which concerns the engineer as much as the question of the ultimate load. Materials are never intended to be stressed to anything approaching the ultimate load of which they are capable; but the practice is to divide this by an empirical number, as 5, 6, 7, 8, 10, &c., termed a *factor of safety*, and let the quotient denote the maximum *safe load* or *working load* for the material. But scientific testing seeks more accurate results than these. It desires to ascertain the *elastic limit* of a material, and to note the effects of increasing increments of stress in drawing out, making a distinction between the general stretching, which extends over the entire length of the

specimen, and that local extension which takes place in the immediate vicinity of the area of rupture. For every ductile material, under a certain set of physical conditions, there is an elastic limit, and there is, of course, an elastic stress corresponding with that limit. That is, there is a limit at which after the removal of the load the specimen will return to its original length. Or putting it more correctly in other words, up to that limit the extensions or *strains are directly proportional to the stresses*, increasing by regular increments, while beyond that limit the extensions or strains increase more rapidly than the stresses, until as the breaking-down point is approached, the elasticity becomes a vanishing quantity, the strains or deformations being utterly out of proportion in excess of the stresses.

Stress-Strain Diagram.—It is usual to record these physical changes graphically in what is termed the stress-strain diagram (Fig. 62). If we plot the loads of stresses as ordinates 1, 2, 3, &c., and the extensions or strains as abscissæ .1 in., .2 in., &c., the relations of stress and strain from the first application of the load to the point of rupture can be made very clear. During the time the specimen is being stressed within the elastic limit the deformation is represented by the line from *o* to *a*, which, it will be observed, is quite straight. During the stretching of the specimen which goes on during this stage, the extensions are uniform over the whole length, and there is no local contraction at all. The measure of these extensions, always given in pounds per square inch, is called the modulus of elasticity of the material, and is denoted by the letter E. In Fig. 62, *a* marks the limit of elasticity, beyond which, the load being increased, the strains suddenly exceed the stresses, and there is sudden and slight elongation of the material. Immediately following this a great local extension takes place, plotted from *b* to *c*. This point is termed the *yield point* or the *breaking-down point.*

If now the load is still increased, the specimen actually shows an increase of strength. It becomes more rigid, and the stress-strain curve rises to *d*. This is an illustration of the same kind as that afforded by the fact that hammer-hardening wire-drawing, and cold-rolling increases the strength of a material, and raises its limit of elasticity. It also shows that there is a spurious kind of elastic limit, as well as one natural to the normal material, or, as Dr Siemens once said, "you

could teach a bar to carry 10 per cent. more than it would do originally by keeping it under strain for some time." And so the curve gradually rises from *c* to *d*, and then all at once suddenly drops, as the ultimate or breaking stress is reached at *e*, and this breaking stress is something less than that which the bar had sustained a little while previously.

The True or Natural Elastic Limit, then, of a material is that of the material in its ordinary state, when no severe work has been imposed upon it by hammering, cold-rolling, wire-drawing, or loading; the natural limit beyond which the strains and stresses cease to be proportional. Beyond this, new elastic limits may be formed by the imposition of severe work of any kind, but with a *corresponding reduction in ductility*, and in this way the elastic limit may be raised almost to the ultimate or breaking strength. A good illustration of this may be observed in the effect of rolling on plates and bars, thin plates and bars having a higher tensile strength than thick ones. In cold-rolling the effect is especially apparent.

There is a point suggested by this stress-strain diagram which, though neglected in common testing, should be noted by the way, in order to the possession of clear ideas as to what actually takes place in the testing of the specimen. From *o* to *a* the extension is taking place equally along the entire effective length of the specimen. But from *b* to *e* it is taking place on a *reduced section*, due to the drawing out of the material. So that the breaking stress, as usually understood, is based on the supposition that it is acting on the original section of the specimen, which it is not, but is really acting on a much smaller section, reduced by drawing out, so that the stress per unit section is greater than that calculated on the original section of the specimen, which is the usual way of stating the breaking strength. So that, when we say a specimen breaks at, say, 24 tons per square inch, the real fact is that the bar breaks with 24 tons at a section perhaps 25 per cent. less than the square inch, which would make the ultimate stress per square inch as much as 30 tons instead of 24. In Fig. 62 the corrected diagram would be the curved line from *b* to *f*.

The stress-strain diagram for brittle materials, such as cast-iron and crucible steel, would not show the abrupt yield point and rapid curving of the figure. The whole of the curve up to the breaking point would be comparatively regular and comparatively flat. So, in the case of materials intermediate

between the ductile and the brittle, the curve would be a mean between the two. In short, the physical characteristics of each material can be read in the stress-strain diagram. Similar diagrams can be made use of for compressive strains.

Standard Test-Piece.—Fig. 61 illustrates the standard types of test-pieces used in England for wrought-iron and steel. Nos. 1 and 2 are for plates and bars, No. 3 for round rods and forgings. In Fig. 1, A is in the effective length of the bar, its extension under stress being measured between the gauged points *o o*. A is almost invariably 8 in. or 10 in. The width *a* is made so as to give a definite cross-section to the test-piece, and, of course, varies with the thickness of the plate from which the test-piece is cut. It may average $1\frac{1}{2}$ in. in width, and the area of the cross-section may be $\frac{3}{4}$ sq. in. or 1 sq. in. The length B may be about 4 in., to suit the grips of the machine, and the width be about 2 in. Note the curves by which the effective length of the test-piece merges into the ends. Square corners are inadmissible in test-pieces, inviting fracture; and if a specimen were nicked, it would break without extension, and show a crystalline fracture. No. 2 specimen is very commonly used, costing less to prepare than No. 1. The length A may range from 15 in. to 18 in. or 24 in., and the width *a* be adapted to the thickness of the plate, so as to get a suitable cross-section. Gauge points will be marked upon it like those at *o o* in No. 1. No. 3 is turned in the lathe, and the length A is of any suitable length from 2 in. up to 12 in.

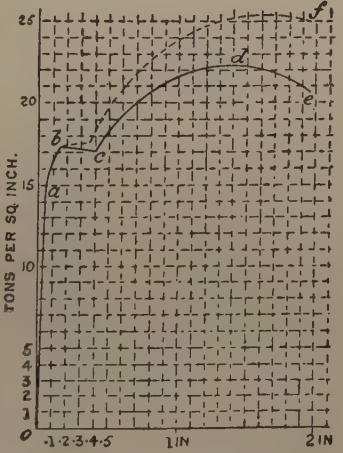


FIG. 62.

Iron Plates—Various Qualities.—The tests demanded for iron plates vary with their qualities, and the purposes to which they have to be applied. Roughly speaking, there are four qualities of iron plates. Bridge and girder quality, B; BB;

and BBB qualities respectively. But these distinctions are somewhat arbitrary, because the same titles or brands will indicate different qualities in the case of different houses. The only guarantee of the exact quality of a given plate or bar is that afforded by actual test.

Before steel had displaced iron, the highest qualities of iron plates were employed for the furnaces, uptakes, cross-tubes, and so forth, of steam boilers, parts exposed to the action of flame and heat. Qualities somewhat inferior were put into the boiler-shells exposed to pressure, but not to excessive heat. The poorer qualities of plates were used for girders, bridges, and ships, and for general constructional work, when, as a rule, the stresses were moderate, scantlings large, and temperature equable. Iron plates are now so seldom called for that most of the old firms have ceased to roll them. Sheets are still listed, being under $\frac{1}{4}$ in. in thickness. The Lowmoor Company still roll plates, the limiting weight being $3\frac{1}{2}$ cwt., the present price being 23s. per cwt.; higher weights and special sizes being charged extras. Cable iron is still in large demand for chains, and for bolts which are subjected to severe stress, as those used for attaching propeller blades to their bosses.

Tensile Tests. — When iron was used for boilers the English Admiralty test was that iron boiler-plates of BB quality were required to have an ultimate tensile strength of 21 tons with the grain, and 18 tons across the grain, and to show an elongation of not less than 10 per cent. in 8 in. In most plates there was a considerable variation taken with and across the grain, and 10 per cent. elongation might be taken as a mean for very good plates, a good plate giving as much as 14 or 16 per cent. with, and 8 or even 10 per cent. across. Such plates were suitable for furnaces and other parts exposed to heat and flame. For boiler-shells, B quality, having about the same tensile strength, but with less elongation, was suitable. The latter was from 8 to 10 per cent. with the grain, and about 7 across. Something, however, depended on the thickness of the plates, and the above remarks applied chiefly to plates of from $\frac{3}{8}$ in. to $\frac{5}{8}$ in. thick; in thicker plates the ductility was less, and they were, therefore, not nearly so suitable for boilers as plates of steel. The Lilleshall Company, one of the best Shropshire houses, who have now ceased rolling plates, guaranteed their iron plates "for general structural purposes" to stand a tensile

strain with the grain of from 20 to 22 tons, across the grain of from 17 to 18 tons, with an elongation of 8 per cent. in 8 in. with the grain, and of 3 to 4 per cent. in 8 in. across the grain. Iron boiler-plates were guaranteed to stand a tensile strain of from 21 to 22 tons with the grain, and 18 to 19 tons across, with an elongation of 15 per cent. in 8 in. with the grain, and 7 per cent. in 8 in. across. But, as previously remarked, there was a great variation, sometimes amounting to as much as several tons, observable in test-pieces cut from the same plate.

The following table, compiled by Mr Kirkaldy, shows by comparison the behaviour of iron plates of different qualities, some steel plates being also included :—

TABLE II.

SUMMARY OF TESTS OF IRON AND STEEL PLATES, *vide* "MERCHANT SHIPPING EXPERIMENTS ON STEEL."

Description.	Thickness of Plates.	Lengthway.			Crossway.		
		Mean Ultimate Stress per sq. inch.	Mean Contraction of Area at Fracture.	Mean Ultimate Extension in 10 inches.	Mean Ultimate Stress per sq. inch.	Mean Contraction of Area at Fracture.	Mean Ultimate Extension in 10 inches.
	Inch.	Tons.	P. Cent	P. Cent.	Tons.	P. Cent.	P. Cent.
Iron Ship Plates -	$\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$	22.01	5.4	5.7	—	—	—
Iron Boiler Plates, Ordinary Quality	$\frac{1}{2}$, $\frac{3}{4}$, 1	21.15	13.07	9.6	18.48	4.41	3.2
Yorkshire Wrought-Iron Plates -	$\frac{3}{8}$, $\frac{1}{2}$, $\frac{5}{8}$	21.3	20.6	16.7	20.3	14.7	11.2
Steel Plates of Steel Co. of Scotland -	$\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, 1	29.3	49.1	28.2	29.2	40.3	25.5

All tensile tests are made either on prepared pieces like Fig. 61, No. 1, page 41, or on shearings like Fig. 61, No. 2, of from 18 in. to 24 in. in length, and of any suitable width. In no case, however, should the area of a cross-section of a test-piece be such that a greater stress than 60 tons will be required to break it, because 60 tons is the maximum pull which most testing machines are capable of exerting.

The products of the Yorkshire houses, of course, stand alone. The following Table gives a scale of tests of Lowmoor iron of various sections :—

SCALE OF TESTS OF LOWMOOR IRON.

	Contraction per cent.	Tons per sq. in.	Elongation per cent. in 8 inches.
Plates, with the grain - - -	20	22	17
Plates, across the grain - - -	15	20	12
Bars, 1 in. and under, in sectional area - - - - - -	50	23	27
Bars, from 1 in. to 4 in., in sectional area - - - - -	45	22	25
Bars, from 4 in. to 8 in., in sectional area - - - - -	40	22	23
Bars, 8 in. and above, in sectional area - - - - - -	40	21	22

There is nothing better for boiler furnaces, for railway hooks and drawbars, for axles, cranks, and forgings, subject to sudden shocks and stresses; but then its price, about double that of the best Shropshire iron, precludes its general use.

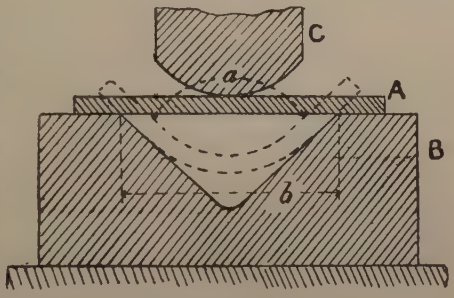
Forge Tests.—The merely tensile tests are not the only ones employed; nor can they be employed at all in small workshops destitute of testing machines. In shops, and in official requirements also, what are termed "forge tests" are used—that is, specimens are variously bent, punched, drifted, to show their ductility, fibre, and homogeneity. These tests demonstrate admirably the qualities of iron and steel to a practised eye. The tests are hot or cold.

The following cold-forge tests show the relative difficulty of bending thick plates. For B iron plates the English Admiralty tests were as follows:—$\frac{1}{4}$ in. plates must bend with the grain to an angle of 65°, and across to an angle of 20°; $\frac{1}{2}$ in. plates, 30° with, 10° across; $\frac{3}{4}$ in. plates, $17\frac{1}{2}$° with, 5° across. Similarly, BB plates must bend as follows:—$\frac{1}{4}$ in. thick, 70° with, 30° across; $\frac{1}{2}$ in. plates, 35° with, 18° across; $\frac{3}{4}$ in. plates, $22\frac{1}{2}$° with, 10° across; 1 in. plates, 15° with, 5° across.

The usual method of taking a test is to cut a strip of the plate to be tested, and bend it hot or cold, as the case may be, to the definite radius suitable for the thickness. The strip A, Fig. 63, is generally laid upon a block, B, hollowed out to the width *b*, and placed under the steam-hammer, and a tup, C, with a convex end, brought down upon it, until it is bent to

the angle *a*. It is then removed and closed with the hammer upon the anvil to the shape A A below. It is better to plane the edges of the strips before bending, otherwise they are liable to crack.

Nicking Test for Fibre.—Another test is for fibre, Fig. 64. The specimen is nicked across, and then bent. The nicking severs the fibres, and the quality of the iron is judged by the aspect of the torn surface, whether granular or fibrous, or dull or lustrous. Good iron, when fractured in this way, should be fibrous and bright.



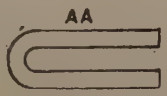


Fig. 63.

Fig. 64.

Fig. 65.

Section-Irons.—For the various section-irons, the tests usually employed are forge tests. For iron bars, angles, and tees, the strength is about a ton over that of plates, or, say, 22 tons with the grain. There are different qualities, and it is necessary when ordering to state if special qualities are required. The common forge tests for bars, angles, tees, and channels are the following:—

Forge Tests—Hot and Cold.—For hot tests, bars of B quality are punched with two holes one-third the diameter of the bar, at distances of one-and-a-half and three diameters respectively from the end of the bar, the holes being at right angles with each other. The holes are then drifted out to one diameter of the bar, Fig. 65.

Thin flats of $\frac{3}{4}$ in. and under are required to bend to a radius of three times their thickness, with the grain, without fracture. The ends of the bars, after punching, must admit of being split and turned back without fracture.

The ram's horn test, Fig. 66, is another common hot test. The bar or rod A has an elliptical hole punched through it near one end, with a punch whose width is one-third of that of the diameter of the iron. The hole is then drifted out to one-and-a-quarter times the diameter of the iron. A slit is then cut down from the end to meet the drifted hole, B, and the iron is opened out and turned back upon itself, C.

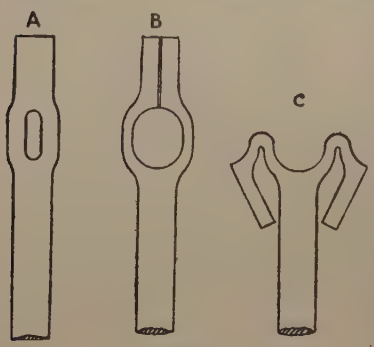


FIG. 66.

A cold forge test for B and B B qualities is to nick the bar and bend it round double, when the quality of the iron will be apparent by the aspect of the fracture. The fracture may be wholly fibrous or silky, indicative of good iron; or chiefly crystalline, showing iron of bad quality; or mostly fibrous, with granulation in patches, indicating iron of average quality.

Forge tests for angle-iron, Fig. 67, A, consist in bending it hot as in B, C, and in flattening it, D, and in bending the end over. A cold test is to cut off a piece of one flange, notch it, and bend cold to show the fibrous or crystalline character. For tee-iron, Fig. 68, A, the cold test is as for angle-iron; the hot tests consist in bending as in B, C, D. Similar tests are employed for channel-iron and other sections.

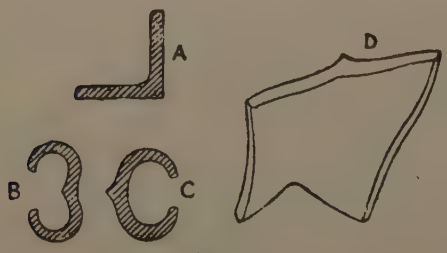


FIG. 67.

Mild Steel—Various Qualities.—We may roughly

average the different qualities of mild steel, which designation, of course, excludes the steels that temper, into about four different kinds. There is the ship and bridge quality; the ordinary boiler quality; the softer boiler quality, suitable for flanging and welding, and often used for parts exposed to flame; and a superior special quality suitable for locomotive fire-boxes, and parts of boilers exposed to flame.

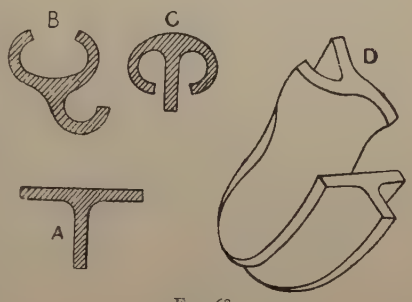


FIG. 68

British Admiralty.—*Ship Plates.*—Strips cut lengthwise or crosswise to have an ultimate tensile strength of not less than 26 and not exceeding 30 tons per square inch of section, with an elongation of 20 per cent. in a length of 8 in.

Bending Tests.—Strips cut lengthwise or crosswise, $1\frac{1}{2}$ in. wide, heated uniformly to a low cherry red and cooled in water of 82° Fahr., must stand bending in a press to a curve of which the inner radius is one-and-a-half times the thickness of the steel tested.

The ductility of every plate, &c., is to be ascertained by the application of one or both of these tests to the shearings, or by bending them cold by the hammer. One plate, &c., to be taken for testing from every invoice, provided the number does not exceed fifty. If above that number, one for every addition of fifty or portion of fifty. Steel may be received, or rejected, without a trial of every thickness on the invoice.

Boiler-Plates—Tensile Test.—Strips are to be cut from every plate and are to stand the following tests:—Strips cut lengthwise or crosswise are to have an ultimate tensile strength per square inch of section—(*a*) Shell and other plates not exposed to flame, which will not be flanged, not exceeding 30 tons nor less than 27 tons, with an elongation of 20 per cent. on a length of 8 in.; (*b*) Front and saddle plates and other plates which are to be flanged, fire-box and other plates exposed to flame, not exceeding 27 tons and not less than 24 tons, with an elongation of 25 per cent. on a length of 8 in.

Strips cut lengthwise or crosswise, 1½ in. wide, heated uniformly to a low cherry red and cooled in water of a temperature of 82° Fahr., must stand bending double in a press to a curve of which the inner radius is one-and-a-half times the thickness of the steel tested. Strips from plates for fire-boxes and other parts exposed to flame are, in addition, to be tested by welding and forging, and some of the welded pieces are to be broken in the testing machine to ascertain the efficiency of the welding. The pieces cut out for testing are all to be cut in a planing machine, are to have the sharp edges removed, and are to be of parallel width for at least 8 in. of length.

Forgings—Tensile Test.—To be not less than 28 tons per square inch, with an extension in 2 in. of length of at least 27½ per cent., and a limit of elasticity of not less than 55 per cent. of the ultimate strength. *Bending Test.*—Bars of the same metal, 1 in. square, should be capable of being bent cold without fracture through an angle of 180° over a radius not greater than ⅝ in.

Board of Trade.—The only steel which is tested by the Board of Trade surveyors is that which has to be used in the construction of marine boilers. The testing is done at the steel-makers' works.

Tensile Test.—Furnace plates and plates exposed to flame, 26 to 30 tons per square inch, with 20 per cent. elongation in 10 in. Shell-plates, butt-straps, and compensating rings (unless otherwise arranged), and plates not exposed to flame, 27 to 32 tons per square inch, with 20 per cent. elongation in 10 in. The tensile strength and elongation are stamped on every plate. *Bending Test.*—From every plate exposed to flame a shearing is taken, heated to a low cherry red, and cooled in water of 82° Fahr. It must then stand bending to a curve, the inner radius of which is equal to one-and-a-half times the thickness of the plate. In the case of shell-plates and plates not exposed to flame, a test piece is taken from each plate and bent cold to a curve, the inner radius of which is equal to one-and-a-half times the thickness of the plate.

In the case of boiler-plates exceeding 20 ft. long, and exceeding 6 ft. wide, or 2½ tons in weight, there should be a tensile test from each corner; when over 15 ft. and under 20 ft. long by 6 ft. wide, one tensile test is taken from each end of the plate, and in both these cases the tests are made in

presence of a Board of Trade surveyor. In all other cases a tensile test is made on every plate, and 25 per cent. of the tests of various thicknesses are made in presence of the surveyor, the others being made by the steel-makers.

Lloyd's Register.—Both ship and boiler steel are tested by Lloyd's surveyors. Boilers may be built under survey, although the ship for which they are intended is not classed.

Boiler-Plates—Tensile Test.—26 to 30 tons per square inch, and 20 per cent. elongation in 8 in. Shell-plates, 28 to 32 tons per square inch, except when flanged or welded, when they must not exceed 30 tons per square inch. *Ship Plates—Tensile Test.*—28 to 32 tons per square inch, and 16 per cent. elongation in 8 in. on plates below $\frac{5}{20}$ in. in thickness, and 20 per cent. on those above that thickness. *Ship Angles and Beams—Tensile Test.*—28 to 32 tons per square inch, and 20 per cent. elongation in 8 in. But angles, frames, and beams may have a maximum tensile strength of 33 tons per square inch, provided they be capable of standing the bending test and of being sufficiently welded. In addition to the temper tests required for every plate and angle, cold bend tests are to be made from each plate or bar tested for tension; also from all garboard plates and all plates where it is known they are to be flanged. In addition to this, samples of plates and bars should be subjected to cold bending tests at the discretion of the surveyors.

Bending Test.—A temper bend is taken from every plate, bar, &c., both for ship and boiler material, and is tested in presence of the surveyor. The test pieces are heated to a low cherry red and cooled in water of 80° Fahr. They must then stand bending to a curve, the inner radius of which is one-and-a-half times the thickness of the piece.

British Corporation.—Both ship and boiler steel are tested by British Corporation surveyors. Boilers may be built under survey, although the ship for which they are intended is not classed.

Boiler Plates—Tensile Test.—Plates intended for the cylindrical shells and butt-straps are to have an ultimate tensile strength of not less than 28 tons or more than 32 tons per square inch, with at least 20 per cent. extension in 8 in. of prepared section. Plates which have to be flanged or welded are to be tested from 26 tons to 30 tons per square

inch in tensile strength with not less than 23 per cent. extension in 8 in., and plates for furnaces may be in tensile strength from 26 to 30 tons per square inch with not less than 23 per cent. extension in 8 in.

Ship Plates and Angles—Tensile Test.—Strips cut from the plate or bar to have an ultimate tensile strength of not less than 28, or more than 32 tons per square inch of section, with an elongation of at least 20 per cent. in 8 in. of prepared section. Frames, beams, and floor plates will be accepted up to 33 tons per square inch in tensile strength with not less than 20 per cent. extension in 8 in. Garboard strake plates, marked so as to be easily identified by the surveyors at the manufactory and in the shipyard, will be accepted of a lower tensile strength of not less than 26 tons, with an elongation of at least 23 per cent. in 8 in.

Bending Test.—A cold or temper bending test is taken from every plate, bar, &c., both for ship and boiler material, and tested in presence of the surveyor. The test resembles those previously stated.

When ordering steel plates, angles, &c., it is very essential that the particular purposes for which they are required should be stated by the purchaser, otherwise it is impossible for the makers to fulfil the order in a satisfactory manner. It is also necessary to say what particular survey the steel has to pass. Then the steel firms usually arrange for the visits of the surveyors, and the purchaser receives his order duly passed and branded. Fig. 69 shows the brands in common use. They indicate that the steel has passed the Board of Trade Survey, Lloyd's, Bureau Veritas, Germanischer Lloyd's, Registro Italiano Surveys, and British Corporation, in their descending order.

Fig. 69.

In the absence of any such official inspection, the steel firms mark the material with one of their own private brands, indicative of its special qualities. All plates, angles, &c., are numbered and stamped consecutively in the order of rolling, and the same numbers are stamped on the test-pieces cut from them. By this means the whole history of a plate or bar can be traced from the furnace charge.

Manufacturers' Qualities.—The Governing Bodies to

whose tests British manufacturers have to conform, are those just stated. But for general requirements, when the tests of these bodies, or specifications are not worked to, the steel firms make various qualities, branded with letters and devices known in the trade. Thus, the Dalzell Steel and Iron Works have the following brands:—*Boiler Strength.*—26 to 30 tons, with not less than 20 per cent. extension in a length of 10 in. *Boiler Fire-Box.*—Strength, 24 to 28 tons, with not less than 20 per cent. extension in a length of 10 in. *Boiler Shell.*—Strength, 27 to 32 tons, with not less than 20 per cent. extension in 10 in. *Special High Tensile Boiler Steel.*—Strength, 34 to 38 tons, with not less than 20 per cent. extension in 10 in. *Ship Steel.*—Strength, 28 to 32 tons, with not less than 20 per cent. extension in 8 in.; and for ship angles and deck beams, strength 28 to 33 tons, with not less than 20 per cent. extension in 8 in. *Special High Tensile Ship Steel.*—Strength, 34 to 38 tons, with 20 per cent. extension in 8 in.; elastic limit, 20 tons per square inch. *Bridge Steel.*—Strength, 27 to 31 tons, with not less than 20 per cent. extension in 8 in. Also a special high tensile steel, *Boiler or Ship quality*, of 36 to 40 tons tensile stress, with an elastic limit of not less than 20 per cent. on a length of 8 in. The Steel Company of Scotland have the following:—First, a steel of ordinary quality, suitable for ship, tank, and bridge-plates, angles, bars, rails, &c. Second, a better quality, made from selected material, with ordinary treatment, suitable for boiler-plates, bridge-plates, forgings, tyres, wire rods, &c. Third, a finer quality, made from selected material, with special treatment, suitable for welding and flanging, deep stamping, boiler furnaces, fire-boxes, and tubes, for special forgings, axles, tyres; and general engineering purposes, wire, rods, springs, smith's tools, &c. Fourth, a very fine quality suitable for all special purposes. All the foregoing are made in various degrees of hardness. Besides these there are brands of nickel steel, chrome steel, and a special brand which is calculated to resist corrosion. These brands can be relied on to fulfil the purposes named, being tested and stamped by the firm, and they are accepted by the Governing Bodies, as they are equivalent to the fulfilment of their own special tests.

It is not only necessary to take tests of materials, but to

observe certain precautions, and to insist on certain stipulations as well. Where large quantities of material are ordered, it is usual to employ an inspector at the steel works, and to test the steel at the works. The same plates and bars can be made to exhibit very different qualities by different modes of treatment. It is always understood that tests are to be made on steel in the normal condition—that is, just as it leaves the rolls. But it is possible to subject plates to such treatment that their tensile strength can be diminished, with considerable increase of elongation, or their strength can be increased, with corresponding diminution of elongation. To effect the first, a process of annealing is resorted to, the plates being heated to a bright red, and allowed to cool either on the floor of the mill or in the furnace. To effect the second, the plates are heated to a bright red and cooled in water of a given temperature. Good firms would not resort to these devices.

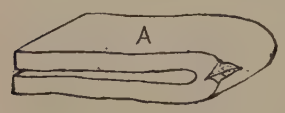


FIG. 70.

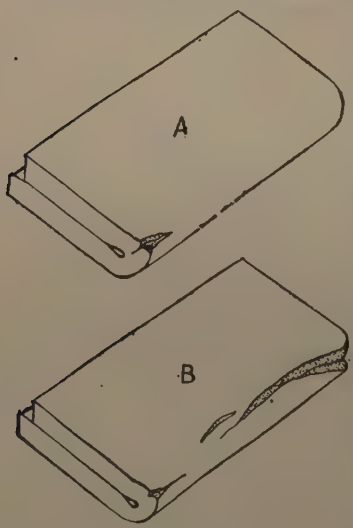


FIG. 71.

Forge Tests—Hot and Cold.—Figs. 70 and 71 are drawn from pieces of steel plate of two different qualities, with, and across, the grain. These specimens show the difference in good and in inferior plate, and in the ductility in the two directions. All the specimens were bent cold. Fig. 70 is a comparatively common brand of boiler steel; A bent with, B across the grain, nearly, but not quite, double. The first is fractured for about one-third of the width; the second across the whole width. Fig. 71 is a very good

quality of boiler steel, bent quite double. A, bent with the grain, is not fractured, except at one corner; B, bent across the grain, has cracked considerably. All the strips are $\frac{3}{8}$ in. thick. The edges were not planed in either case. If they had been planed, A in each case would probably have shown no fracture at all. The fracture is entirely granular in each case. A silky fibre would not be developed at all in such tests as these. In the very best steel a silky fibre will be developed in a purely tensile test, but not otherwise.

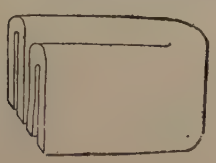


FIG. 72.

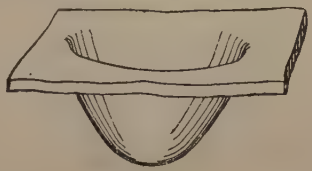


FIG. 73.

Another severe cold test for good steel plate is shown in Fig. 72, the strip being first bent double, and then redoubled. A common hot test is illustrated in Fig. 73, the specimen being dished deeply as shown, a measure of its capacity for flanging.

For sections other than plates, various forge tests are employed. Both rivet iron and steel have a greater tensile

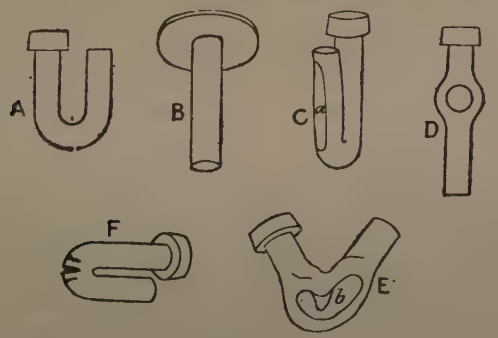


FIG. 74.

strength than iron and steel plates. Iron has about 24 tons ultimate strength, with an elongation of about 25 per cent. in 10 in. Tests for iron and steel rivets are as follows :—In iron

they should admit of being bent cold around a bar of diameter equal to that of the rivet, Fig. 74, A. The head should bear hammering hot until it is flattened out to two-and-a-quarter times the diameter of the shank, and $\frac{1}{8}$ in. in thickness, B. Rivets should bend double when hot, C. The shank should bear flattening and punching hot, with a hole equal to the diameter of the shank, D. Steel rivets have a tensile strength of from 26 to 30 tons, and an elongation of from 25 to 30 per cent. in 10 in. They should admit of being bent double when cold, like C in the figure. The flattening shown at *a* illustrates the appearance which a rivet thus bent shows, the result of the hammer-blows, and is an excellent illustration of the softness and ductility of rivet steel; E affords a further illustration of the ductility of rivet steel, the rivet having been bent cold, after the punching and drifting out of the hole *b*. Extreme ductility is required in rivets more than high tensile strength, because of the shrinkage stresses due to cooling, which are considerable in the longer rivets. Moreover, rivets are not subject to direct tensile stresses so much as to shearing action. Soft steel rivets are much better than iron, excepting those made of the Yorkshire irons, which are very costly—about £23 a ton against £9 a ton for steel rivets, dependent on size. To illustrate the difference between ordinary iron and steel rivets, I have drawn at F an iron rivet bent double cold, and cracked in the process. Iron rivets cannot be depended on to bend more than shown at A without cracking, while those of steel will almost invariably bend cold, as shown at C, until they are not only bent, but considerably flattened as well. Rivets are also nicked slightly, and then bent double cold, in order to observe the nature of the fracture, whether silky or granular, or partly one, partly the other.

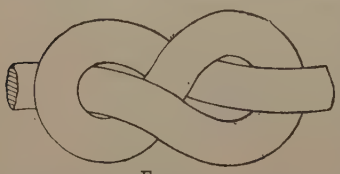


FIG. 75.

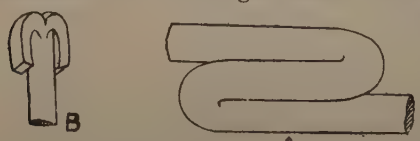


FIG. 76.

Steel rod should stand knotting cold, one illustration of which is shown at Fig. 75. It should stand bending and re-

bending close, like Fig. 76, A, and should bear dividing and turning back close upon itself, B. A steel bar should stand punching and drifting hot without cracking, until its bounding

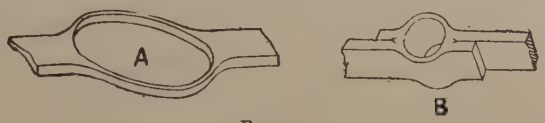


FIG. 77.

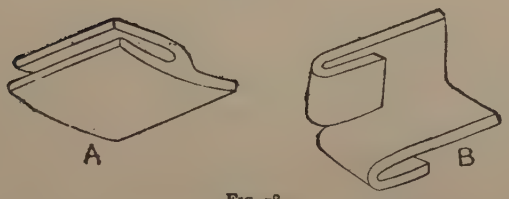


FIG. 78.

edges are of an extreme tenuity, as shown in Fig. 77, A. After two bars are welded, they should stand punching and drifting in the welded joint without the weld giving way, B. Steel of tee section should bear doubling cold one rib upon another, as shown in Fig. 78, A, treatment which iron tees would not stand. Angle-iron should bear slitting and doubling back upon itself, as at B.

Boiler Stays, and Rivet Bars.—For some years after steel came into general use for boiler plates, the practice was retained of using iron rivets—rivet iron of BB, or BBB quality for commercial boilers, and iron of Lowmoor or other Yorkshire brand for special specifications. The latter is still employed when cost is not considered, but steel is generally employed both for rivets and stays. The tests for Lowmoor bars are given at p. 48.

British Admiralty.—*Boiler Stays, and Rivet Bars:*—*Tensile Test.*—A piece from one bar from every charge, or one from every fifty bars or portion of fifty, to be tested as follows:—*Boiler Stays.*—27 to 30 tons per square inch with an elongation of not less than 20 per cent. in a length of 8 in. *Boiler Rivet Bars.*—24 to 27 tons per square inch. *Ship Rivet Bars.*—26 to 30 tons per square inch, with a minimum elongation of not less than 25 per cent. in a length of 8 in. For all rolled round, square, and flat bars, also half round and segmental bars, the tensile test is 30 to 35 tons per square inch with a minimum elongation of 20 per cent. in a length of 8 in.

CHAPTER V.

LIMITING DIMENSIONS AND WEIGHTS OF MATERIALS.

Maximum Dimensions—Plates—Area, Length, Width.—Extras.—Lists.—Dimensions of Rolled Sections.—Extras.—United Inches.

I AM going to devote this chapter to the consideration of a subject which may be termed the commercial, rather than the mechanical, aspects of iron and steel plates and sections. It has to do with the ordering of materials, and not with their manipulation. It is essential to possess some knowledge of what sizes and weights are obtainable at ordinary prices, because it is frequently desirable to utilise the largest available, in order to save the cost of making joints. Frequently joints are made by riveting, not because they are wanted at all, but simply because they cost less than single plates would do. Information of this kind is only to be obtained from the price-lists of the iron and steel manufacturers, which are supplied to the trade.

Maximum Dimensions—Plates.—Each plate has three maximum dimensions, varying according to its thickness, viz., a maximum length, a maximum width, and a maximum area in square feet.

All plates ordered must be within the maximum of each dimension. For example, a $1\frac{1}{2}$ in. plate, 20 ft. long by 11 ft. wide, has an area of 220 sq. ft., and is within the dimensions allowed, but a plate of the same thickness, 40 ft. long by 10 ft. wide, would have an area of 400 sq. ft. In this case, while the length and the width are both within the maximum allowed, the area is over the maximum allowed, and either the length or the width would require to be reduced to bring the area down to 370 sq. ft. (See list.)

If, however, it was of great importance to have the plate

rolled to its full size, this could probably be done by special arrangement and the payment of a small additional charge.

Examples of these are given in the following pages.

David Colville & Sons Limited.

MAXIMUM DIMENSIONS TO WHICH STEEL PLATES ARE ROLLED.

Diameters in inches.	Thicknesses in inches.	Lengths in feet.	Widths in inches.	Areas in square feet.
67	$\frac{3}{16}$	40	65	165
81	$\frac{1}{4}$	45	77	205
85	$\frac{5}{16}$	47	82	215
87	$\frac{3}{8}$	50	86	240
97	$\frac{7}{16}$	50	96	240
109	$\frac{1}{2}$	50	108	250
120	$\frac{9}{16}$	50	118	260
128	$\frac{5}{8}$	55	126	270
134	$\frac{11}{16}$	60	132	280
140	$\frac{3}{4}$	60	138	320
144	$\frac{7}{8}$	70	142	370
146	1	75	144	310
			141	400
146	$1\frac{1}{4}$	70	142	380
			140	450
145	$1\frac{1}{2}$	55	140	370
145	$1\frac{3}{4}$	55	140	320
144	2	50	140	300

By special arrangement larger, thicker, and heavier plates may be made.

Subject to alteration without notice.

Extreme of each dimension of Steel Plate rolled:—

Length - - - -	75 feet.
Width - - - -	12 feet 2 inches.
Thickness - - -	12 inches.

Max. Thickness sheared - - - -	2 inches.
,, Weight sheared - - - -	11 tons.
,, Thickness cut by band saw - -	24 inches.
,, Weight cut by band saw - -	25 tons.

Ingots, Blooms, Slabs, &c., cut by band saw up to 36 inches by 40 inches.

The Steel Company of Scotland Limited.

Thickness.	Maximum.				Thickness.	Maximum.			
	Length.		Breadth.	Area.		Length.		Breadth.	Area.
In.	Ft.	In.	Ft. In.	Sq. ft.	In.	Ft.	In.	Ft. In.	Sq. ft.
1 1/16	14	0	4 0	28	1 9/16	50	0	9 2	210
3 3/32	14	0	4 2	32	1 5/8	50	0	9 8	220
1/8	20	0	4 6	54	1 11/16	50	0	10 2	230
3 5/32	20	0	4 8	60	1 3/4	50	0	10 8	240
1 3/16	24	0	5 0	75	1 7/8	50	0	11 0	250
1/4	30	0	5 6	100	1	50	0	11 4	250
1 5/16	34	0	6 0	120	1 1/8	50	0	11 4	250
3/8	36	0	7 0	135	1 1/4	50	0	11 4	250
1 7/16	40	0	7 6	150	1 3/8	50	0	11 4	240
1/2	48	0	8 4	165	1 1/2	50	0	11 4	230

The Park Gate Iron and Steel Company Limited.

Thickness.	Rectangular Plates.						Circular Plates.	
	Length without extra.		Maximum Length.		Width without extra.	Maximum Width.	Maximum Area.	Maximum Diameter.
In.	Ft.	In.	Ft. In.		Ft. In.	Ft. In.	Ft.	Ft. In.
1 1/16	8	0	8 0		4 0	4 0	32	4 0
3 3/32	8	0	8 0		4 0	4 0	32	4 0
1/8	12	0	12 0		4 6	5 0	50	5 0
1 3/16	16	0	20 0		5 0	5 6	72	6 0
1/4	20	0	40 0		6 0	6 6	100	7 0
3/8	30	0	40 0		6 6	7 0	100	7 6
1 7/16	30	0	40 0		7 0	7 6	130	8 0
1/2	30	0	45 0		8 0	8 6	160	9 0
9/16	30	0	50 0		8 0	9 6	200	10 0
3/4	30	0	50 0		8 0	10 6	250	11 0
7/8	30	0	50 0		8 0	11 6	230	11 6
1	30	0	60 0		8 0	11 6	200	11 6
1 1/8	30	0	60 0		8 0	11 6	180	11 6
1 1/4	30	0	50 0		8 0	11 6	160	11 6
1 3/8	30	0	50 0		8 0	11 6	130	11 6
1 1/2	30	0	50 0		8 0	11 6	120	11 6

William Beardmore & Company Limited.

Thickness.	Length.	Width.		Area.
		Rectangular.	Diameter.	
Inches.	Feet.	Inches.	Inches.	Feet.
$\frac{1}{16}$	12	48	56	36
$\frac{3}{32}$	12	48	58	40
$\frac{1}{8}$	16	59	60	56
$\frac{5}{32}$	22	59	60	70
$\frac{3}{16}$	30	65	80	120
$\frac{7}{32}$	32	78	84	140
$\frac{1}{4}$	35	80	92	160
$\frac{5}{16}$	35	86	92	180
$\frac{3}{8}$	35	96	108	200
$\frac{7}{16}$	40	114	128	240
$\frac{1}{2}$ to $1\frac{1}{4}$	40	130	136	250
$1\frac{3}{8}$ to $1\frac{3}{4}$	40	136	138	260
			138	270

Over $1\frac{3}{4}$-in., Plates can be rolled to any greater thickness.

Consett Iron Company Limited.

Areas in Feet.	Thickness in Inches.	Areas in Feet.	Thickness in Inches.	Areas in Feet.	Thickness in Inches.	Areas in Feet.	Thickness in Inches.
48	$\frac{1}{4}$ to $\frac{3}{8}$	200	$\frac{7}{16}$ to $\frac{1}{2}$	220	$\frac{9}{16}$ to $\frac{5}{8}$	165	$1\frac{1}{16}$ to $1\frac{1}{8}$
80	$\frac{1}{2}$ to $\frac{5}{8}$	200	$\frac{5}{8}$ to $\frac{3}{4}$	200	$\frac{11}{16}$ to $\frac{13}{16}$	155	$1\frac{3}{16}$ to $1\frac{1}{4}$
100	$\frac{3}{4}$ to $\frac{7}{8}$	235	$\frac{7}{8}$ to $1\frac{1}{16}$	200	$\frac{7}{8}$ to $\frac{15}{16}$	135	$1\frac{5}{16}$ to $1\frac{3}{8}$
150	$\frac{1}{2}$ to $\frac{5}{8}$	235	$1\frac{1}{8}$ to $1\frac{3}{16}$	185	1	125	$1\frac{7}{16}$ to $1\frac{1}{2}$
200	$\frac{5}{8}$ to $\frac{3}{4}$	230	$1\frac{1}{4}$ to $1\frac{5}{8}$	175	1	115	$1\frac{9}{16}$ to $1\frac{5}{8}$

Dimensions of Rolled Sections.—The group of figures 79 is drawn to show at a glance the principal rolled sections of iron and steel. We will run over the average, or usual minimum and maximum dimensions in which these sections are obtainable, without specifying the exact dimensions of different houses. It must, however, be remembered that extreme sections are not obtainable at all houses.

Nos. 1, 2, 3 are the commonest forms in which bar iron is rolled, namely, "rounds," "squares," and "flats" respectively. No. 1 is usually rolled from $\frac{3}{16}$ in. to $6\frac{1}{2}$ in. in diameter in iron, and an inch or two larger in steel. No. 2 is rolled from $\frac{3}{16}$ in. to $6\frac{1}{2}$ in., No. 3 from $\frac{3}{8}$ in. to 12 in. wide, and from $\frac{3}{16}$ in. to $2\frac{1}{2}$ in. thick. The dimensions advance by $\frac{1}{32}$ in., $\frac{1}{16}$ in., $\frac{1}{8}$ in., and $\frac{1}{4}$ in., as they range from the smaller up to the larger bars, and they can generally be obtained "bare," "exact," or "full in section." "Snedshill" *squares* advance from $\frac{3}{8}$ in. to $1\frac{1}{2}$ in. by sixteenths; from $1\frac{1}{2}$ in. to 4 in. by eighths; from 4 in. to 5 in. by quarter-inches; and from 5 in. to 6 in. by half-inches. Snedshill *rounds* advance from $\frac{3}{8}$ in. to 1 in. by sixty-fourths; from 1 in. to $3\frac{1}{4}$ in. by thirty-seconds; from $3\frac{1}{4}$ in. to 5 in. by eighths; and from 5 in. to 6 in. by quarter-inches.

No. 4 is common *angle-iron*. The dimensions vary both in width of flanges, A A, and in their thickness, *a a*. A ranges from $\frac{3}{4}$ in. or 1 in. to $4\frac{1}{2}$ in.; and *a a* from $\frac{1}{8}$ in., $\frac{1}{4}$ in., or $\frac{3}{8}$ in. in the smaller sizes, to from $\frac{3}{8}$ in. to $\frac{3}{4}$ in. in the larger. Steel angles can be had up to $8\frac{1}{2}$ in. by $8\frac{1}{2}$ in. No. 5 is an *unequal-sided angle*, and will range from $1\frac{1}{4}$ in. on flange A, and 1 in. on flange B, to 6 in. on flange A, and 4 in. on flange B, the thicknesses *a a* being about the same as in the previous figure. Steel angles can be had up to 14 in. by $3\frac{1}{2}$ in. No. 6 is *square-throated angle*, rolled up to about $2\frac{1}{2}$ in. by $2\frac{1}{2}$ in. No. 7 is *round-backed angle*, rolled equal-sided from $2\frac{1}{2}$ in. by $2\frac{1}{2}$ in., to 4 in. by 4 in., or 5 in. by 5 in.; and in a range of thicknesses from $\frac{3}{16}$ in. minimum in the smaller, to $1\frac{1}{4}$ in. maximum in the larger. Nos. 8 and 9 are termed *open* angles and *acute* angles respectively, and are rolled in a few sizes only, ranging from about 2 in. to 3 in., both equal and unequal, and in slightly varying thicknesses. Very few houses roll these at all. Nos. 10 and 11 are *bulb* angles, always unequal-sided, and with the bulb *c* sometimes inside, sometimes outside. They will range from 5 in. on side A, and $2\frac{1}{2}$ in. on side B, to

9 in. on side A, by $3\frac{1}{2}$ in. on side B. The thicknesses *a a* vary, as in other angles. The thickness *c* of the bulb is rather more than twice that of the web *a*. Besides these, some very

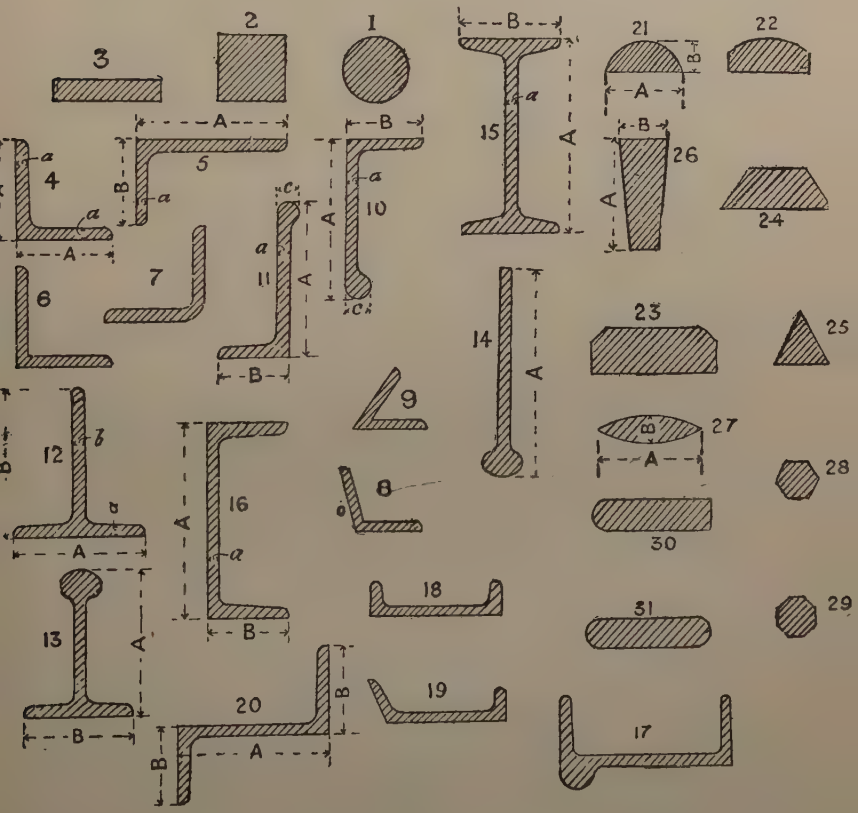


FIG. 79.

special angles are also rolled for specific purposes; but I cannot take account of them here.

After the angles, the tees are of much importance. No. 12 shows the common form of *tee*. The sectional dimensions

of these tees vary widely. Thus A and B may be equal, or A may be wider than B, or the reverse, and *a* may be thinner than *b*, or the reverse. It all depends on the specific uses to which the sections have to be put. In a general way I will only remark that these tees can be had from $\frac{3}{4}$ in. in the dimensions A and B, up to 7 in. by $3\frac{1}{2}$ in.; and in thicknesses, *a*, ranging from $\frac{3}{16}$ in. to $\frac{1}{2}$ in. or $\frac{5}{8}$ in. No. 13 is a *bulb tee*, made only in large sizes, and chiefly in steel. They range from 5 in. in the dimension A, by 4 in. in the dimension B, to 12 in. in A, by 6 in. in B.

Bulb bars or *bulbs* simply are shown at No. 14. These range from $2\frac{1}{4}$ in. to 13 in. in length A, and in various thicknesses.

No. 15 is a very common and highly useful section—the H—*iron*, *joist*, or *girder*. These can be had from 3 in. in the depth A, by $1\frac{1}{2}$ in. in width of flange B, to 24 in. in A, by $7\frac{1}{2}$ in. in B; and in a range of thicknesses, *a*, suitable to the size, and with a variation in thickness of about $\frac{1}{4}$ in. in girders of the same depth and width.

Of almost equal service is the *channel*, No. 16, ranging in size from 3 in. on web A, by 2 in. on flanges B, to 15 in. on A, by 4 in. on B, and with considerable range of thickness. In fact, the thickness, *a*, of the web can be increased almost indefinitely if required. Three modified forms out of several are shown in Nos. 17, 18, and 19.

No. 20 shows a *zed*, or *space bar*. It is made from $2\frac{1}{2}$ in. in the web A, by $2\frac{1}{2}$ in. in flanges B, to 10 in. in A, by $3\frac{1}{2}$ in. in B, the thicknesses ranging from about $\frac{5}{16}$ in. to $\frac{9}{16}$ in. in the minimum and maximum sizes.

The remainder of the group of figures illustrates forms of less general service, though indispensable for some purposes. Nos. 21 and 22 show *convex iron*, the first being *feather-edged*, the second *square-edged*, both used for finish, forming beadings on the edges of plated work. The first is made from $\frac{3}{8}$ in. wide at A, by $\frac{3}{16}$ in. or $\frac{1}{4}$ in. thick at B, to 5 in. wide at A, to from $\frac{1}{2}$ in. to 1 in. thick at B. The second is made from $\frac{7}{8}$ in. to 8 in. wide, and with varying thicknesses at centre and edges. Nos. 23 and 24 are *bevelled irons*, the first made from $1\frac{1}{4}$ in. to $4\frac{1}{2}$ in. wide, with various thicknesses at middle and edges, and various widths at top; the second made from $1\frac{3}{8}$ in. to 2 in. wide, and from $\frac{1}{2}$ in. thick to $\frac{3}{4}$ in. thick respectively. No. 25 is *equal-sided triangular iron*, made from $\frac{7}{8}$ in. to $1\frac{5}{8}$ in. No. 26

is *tapered iron*, from $1\frac{1}{8}$ in. to $3\frac{1}{4}$ in. deep at A, and made from $\frac{7}{32}$ in. to $\frac{7}{16}$ in. at B in the first, to from $\frac{1}{2}$ in. to 1 in. in the last. No. 27 is *oval iron*, made from about $\frac{1}{2}$ in. at A, by $\frac{3}{8}$ in at B, to $1\frac{1}{2}$ in. at A, by $\frac{1}{2}$ in. to 1 in. at B. Nos. 28 and 29 are *hexagons* and *octagons* respectively, made only in a few sizes, from about 1 in. to $1\frac{1}{2}$ in. Nos. 30 and 31 are *round-edged flats*, ranging from about $\frac{5}{8}$ in. to $2\frac{1}{2}$ in. wide, by from $\frac{3}{16}$ in. to $\frac{5}{8}$ in. thick.

I have not noticed one-half of the sections of iron and steel which are rolled. To do so would be beside my purpose. But all the usual sections are shown here.

All sectional irons, and steel angles, tees, channels, and girders, are tapered more or less in the depth, due to the necessary taper which is given to the grooves of the rolls.

In very few cases, if any, can the whole of these sections from minimum to maximum be obtained at one house. But they can be obtained of various English and Scotch firms. Some houses make a specialty of the lighter, and others of the heavier sections. And even below and above those named, some sections can be rolled by special arrangement, either by ordering a large quantity, or by paying higher prices. Some of these sections, chiefly the bulb sections, are used mostly in shipbuilding, for deck beams, and kindred purposes. But most of the sections shown are common to all ordinary platers' and boiler-makers' work. They all have to be cut off, bent to various curves and angles, welded and riveted. Into the consideration of these various matters we shall enter immediately.

British Standards.—A series of rolled sections has been standardised both in British and metric dimensions. The makers of rolled sections supply ample data for platers in giving thicknesses, weights per foot run, radii, moments of inertia, least radius of gyration, section modulus, and safe loads for various spans and for struts, by which the labour of calculation is saved or simplified. The standard steel sections range as follows:—Equal-sided angles, from 1 in. by 1 in. to 8 in. by 8 in., with various thicknesses. The metric standard sections range from 15 mm. by 15 mm. to 160 mm. by 160 mm. Unequal-sided angles, from $1\frac{1}{4}$ in. by 1 in. to 10 in. by 4 in. Metric ditto, from 30 mm. by 20 mm. to 200 mm. by 100 mm. Tees from 1 in. by 1 in. to 7 in. by $3\frac{1}{2}$ in. Metric ditto, from 20 mm. by 20 mm. to 200 mm. by 100 mm. Channels from

$3\frac{1}{2}$ in. by $1\frac{1}{2}$ in. to 15 in. by 4 in. Metric ditto, from 30 mm. by 33 mm. to 300 mm. by 100 mm. Joists from 3 in. by $1\frac{1}{2}$ in. to 24 in. by $7\frac{1}{2}$ in. Metric ditto, from 8 mm. by 42 mm. to 600 mm. by 215 mm.

Extras.—It does not follow that because certain sections are rolled, they can be supplied at ordinary prices. There will be as much as £7 or £8 per ton difference in the price of different sections of the same quality of iron or steel.

The extras on steel are many and varied, and concern widths, weights, shapes, thicknesses, tensile strengths, and special surveys.

Widths.—The width, and the area, are the limits of plates. The maximum widths possible given in lists are not rolled at ordinary prices. Thus, the Dalzell Works charge 2s. 6d. per ton extra for every 3 in. or part of 3 in. on plates over 96 in. wide, at $\frac{9}{16}$ in. thick and upwards; over 90 in. wide of $\frac{1}{2}$ in. thickness; over 84 in. wide at $\frac{7}{16}$ in. thickness; and over 75 in. wide at $\frac{3}{8}$ in. thickness.

Weights.—Plates of from 80 cwt. to 120 cwt. are charged 5s. extra for each extra 5 cwt. or part of 5 cwt.; 10s. extra is charged for each 5 cwt. or part of the same over 120 cwt. On heavy plates, therefore, the extras are very large. The weight is the delivered weight, after the plates are sheared ready for dispatch.

Shapes.—All plates which are not rectangular are outside the limits. They are termed sketch plates, when the edges are tapering. It is usual to allow 15 per cent. of these plates free of extras, but beyond that 20s. per ton is charged. Other shapes are charged 25s. extra. They include circular plates, those sheared to templet, or to curved shapes.

Thicknesses.—Ordinary thicknesses range from $\frac{3}{8}$ in. to $1\frac{1}{2}$ in. Those which are thinner and thicker are extras, ranging from 2s. 6d. to 30s. per ton. The highest extras are for thick plates, 20s. being charged for those from $1\frac{5}{8}$ in. to $1\frac{3}{4}$ in., and 30s. for those from $1\frac{3}{4}$ in. to 2 in.

Tensile Strength.—As tensile strengths have a range mostly of 4 tons, sometimes 5, extras are charged when the range is narrowed to 2 or to 3 tons; being 20s. in the first, and 10s. in the second. Extras are also charged for minimum and maximum strengths when these are different from those which are ordinarily required. Minimum strengths for the ordinary grades range from 26 to 28 tons. Therefore any minimum

strengths from 28½ tons to 35 tons are charged extra, being 5s. in the first, and 120s. in the last, with intermediate strengths ranging in proportion. As, too, maximum strengths mostly lie between 28 and 32 tons, extra is charged for maximum strengths of not more than 25 to 27 tons. For the first, 40s. extra is charged, for the last 10s. extra per ton. A minimum elongation of 25 per cent. in 8 in. involves an extra of 15s. per ton. Testing from each corner of a plate is an extra.

Special Surveys.—This relates chiefly to the surveys made by the inspectors of the various Governing Bodies. Extras are also charged for special locomotive boiler-plates. A low limit of sulphur and phosphorus involves an extra. Thus, a phosphorus and sulphur limit of 0.04 per cent. involves a 40s. per ton extra, and a limit of 0.035 per cwt. a 70s. extra. The extras of the Lowmoor iron sections range from about 2s. to 6s. per cwt. in various dimensions, the price increasing with diminution in dimensions. Thus, while rounds of $\frac{5}{8}$ in. and upwards have a basis price of 20s. per cwt., those of $\frac{5}{16}$ in. in diameter are 6s. extra.

Latterly a special high tensile steel has been manufactured, both for boilers and ship work, to Board of Trade, and Lloyd's requirements. (See p. 55.)

United Inches.—The usual way of reckoning angles, tees, and channels in their various forms is in *united inches*—that is, the total section of the angle, tee, or channel. Speaking generally, from 8 to 9 united inches is the limit in iron, 10 in. in the Yorkshire houses, and 11 in. in steel. Over that a charge of 5s. per ton per inch, or part of an inch, is usually made in steel, and 10s. per ton in iron; £1 in the Yorkshire houses. In light sections, extra is charged under about 3 united inches in iron, and from 4 in. to 6 in. in steel; the rates ranging from 10s. to 30s. per ton per inch in iron, and being about 7s. 6d. in steel.

Bulb angles cost about 20s. per ton over plain angles in iron, and 10s. in steel. Tees cost about the same amount over angles. Channels from 25s. to 30s.; round-backed angles about 18s. per ton extra; Z-bars are the same as bulb angles and bulb bars, 10s. per ton over angles.

As a rule the extras are not so heavy in steel as in iron, because the difficulty of rolling sound sections is not so great; from 5s. to 20s. usually covers the extras; 40s. is an exceptionally high rate for steel.

CHAPTER VI.

CUTTING AND STRAIGHTENING PLATES, &c.

Shearing Machines.—Cold Iron Saws.—Ordering Plates.—Sketch Plates.—Sawing Angles, &c.—Cutting Block.—Planed Edges.—Cutting Curved Edges.—Levelling Blocks.—Straightening Plates with the Hammer.—Details of the Process.—Straightening in Rolls.—Straightening Section Irons.—Details.—Straightening Machine.

THE methods of cutting out, straightening, and bending plates and sections will now engage our attention.

Shearing Machines.—Shearing machines are of three types, those used for cutting the edges of plates straight, those for cutting bars, and those for cutting angles. These are sometimes made as separate machines, sometimes in combination. The most common combination is, however, that of punching and shearing machines in the well-known double-ended form, Fig. 80, used for shearing bars and the edges of plates in detail. But this combination is not a desirable one, and is considered objectionable when the heaviest work has to be done (*see* Chap. XVII., pp. 303-305). But its convenience and relative cheapness in first cost, renders the machine the most popular. Angle-cutting attachments also are often inserted in punching and shearing machines, though sometimes in self-contained machines the angle cutters may operate either in a vertical or horizontal direction. The latter is generally preferable, because when the ends of bent angles are cut to length after being curved, it is more convenient generally to let the curve bend in a horizontal rather than in a vertical direction. When an angle-cutting attachment is included in a double-ended punching and shearing machine, it is placed at about the centre, that is midway between the punching and shearing ends, and receives its motion from an eccentric.

The usual types of double-ended shearing and punching machines are shown in Figs. 80, 81, 82, and on page 301.

Fig. 80 illustrates a punching and shearing machine by Messrs F. Berry & Sons. It is belt-driven from line shafting, and is double geared. It will punch up to 1 in. holes through 1 in. plate, 24 in. from the edge; and shear 1 in. plate, 24 in. from the edge. Angles are cut by the blade at the centre.

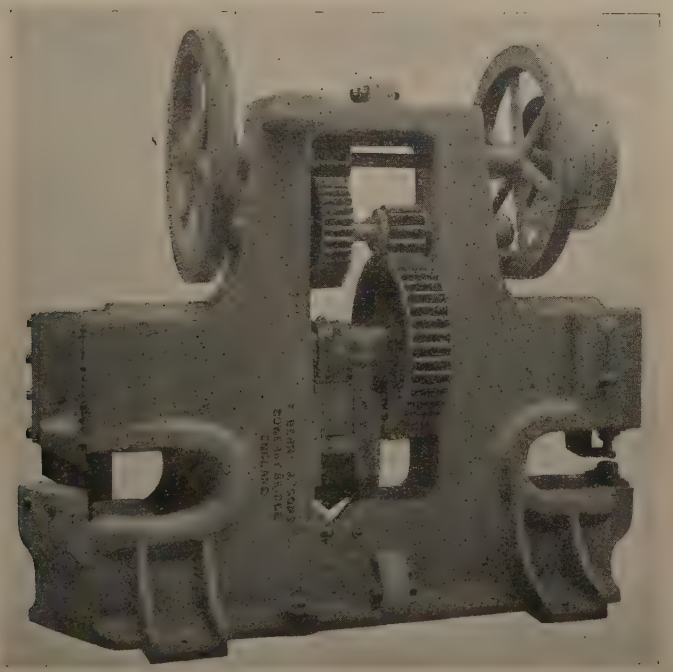


Fig. 80.

Fig. 81 shows a combined punching and shearing machine fitted with jib cranes, the trolleys of which carry pulley blocks for handling the work. The drive is by electric motor, working through double gearing to the main shaft on which the eccentrics are mounted. The machine will shear 1 in. plate, and punch 1 in. holes through 1 in. plate. Messrs Hugh Smith & Co. Ltd. are the makers.

Fig. 82 is a hydraulic double-ended machine, of Messrs

Henry Berry & Co.'s, a type which is much used in preference to the power-driven machines in establishments where hydraulic plant is laid down. There is also an angle cutter placed in the centre of the machine. Both in Figs. 80 and 81 there is this good feature embodied, that the punching gap is much deeper than the shearing gap. In many of the older machines these were made of equal depth, with the result that the

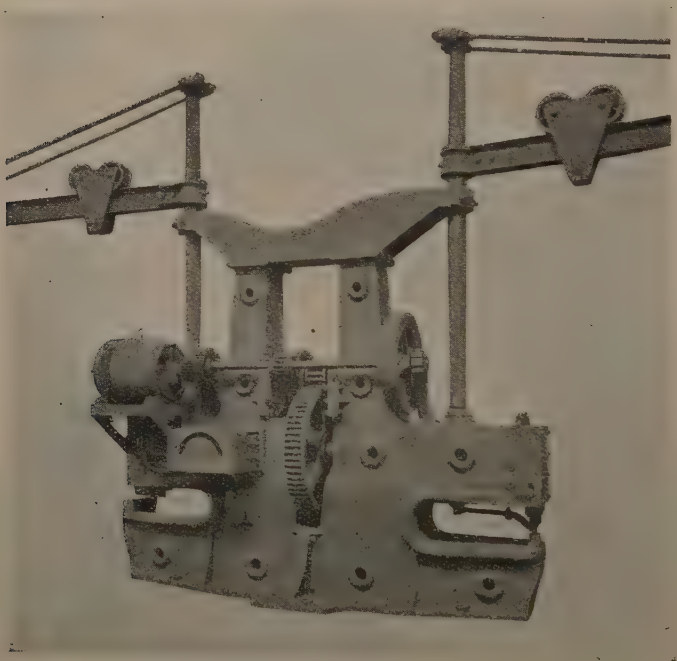


Fig 81.

shearing end of the machine was made needlessly weak, because shearing in a shop is seldom done far from the edge, while punching often has to be done in, or near the middle of a plate.

Some of the plate shears are very massive, having blades 10 ft. or more in length, and being capable of cutting through $1\frac{1}{4}$ in. or $1\frac{3}{8}$ in. steel plate

One of Messrs Rushworth's medium-sized plate shearing machines is shown in Fig. 83; it will cut 6 ft. of plate, $\frac{5}{8}$ in. thick, at one stroke. The driving is effected by fast and loose pulleys on the top shaft, fitted with two flywheels. A double set of spur gears transmit the motion at a slow speed to the eccentric shaft, situated above the shear blade. Eccentric rods from this shaft dip down into recesses in the blade slide, and press upon wedge blocks which convey the pressure to the slide. The blocks can be drawn back by levers on a shaft at the front, so that the movement of the slide is stopped at will.

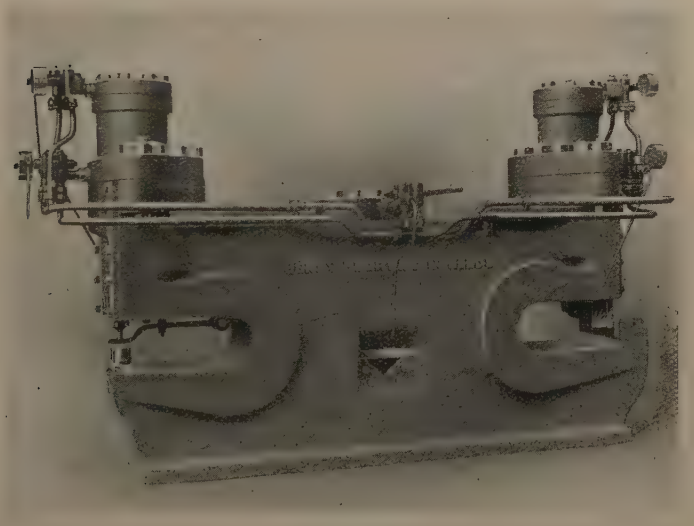


Fig. 82.

Cold Iron Saws.—Cold iron saws are used much now in bridge and girder work. There are two or three main types. The strongest saws are those mounted to slide in the table of a massive square framework. Some of these will cut beams as large as 17 in. by 19 in. The saw is traversed along with its bearings by means of worm gear, driven by belt power, and the length of travel of the saw is the same as the maximum length which it will cut. The diameters of such saws will range from 20 in. to 34 in. The top of the table is provided

with tee-headed grooves, for the purpose of securing the work. For a rather lighter class of work, but still powerful enough for most shops, the Hetherington lever saw is a good machine tool. The saw is carried in a swing frame, pivoted so that the saw can rise and fall in a vertical direction. The work is bolted to the bed plate. The saw is driven by belt power, and bevel and worm gear, and the feed is imparted downwards

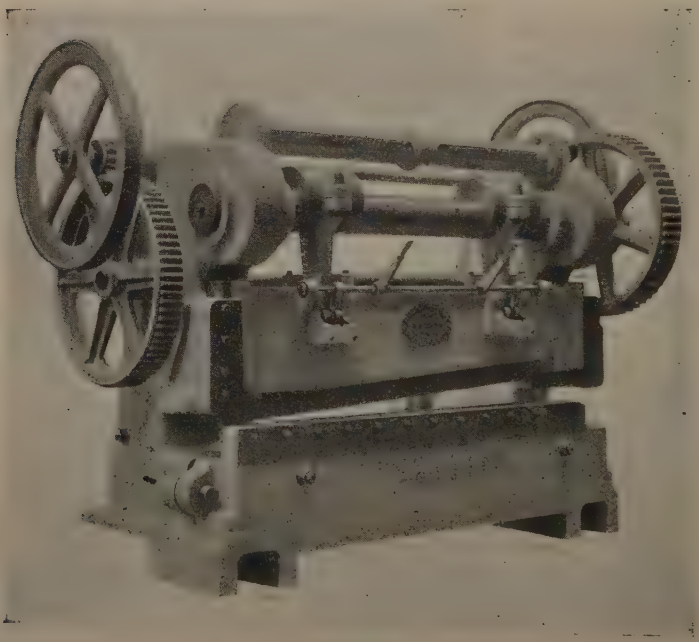


Fig. 83.

by weighting a lever handle, attached to the swing frame. There is a small pump for lubrication.

Ordering Plates.—As regards the cutting of plates, there is relatively little of that done in any but the largest shops. It is usual to order plates to the finished shapes and dimensions required, saving for any small planing allowances that may be necessary. Thus every plate that has to be worked up into a

girder or a boiler is set down in a list, and sent to the rolling mills. And it is usually understood that the *first dimension* of any plate corresponds with the *lengthway* of rolling, and the second with the crossway, even though the first dimension may happen to be less than the second. The reason why plates are ordered to the finished sizes is because the rolling mills have large plate shears suitable for cutting long edges, and engineers' shops as a rule do not possess wide shears of this kind, the limit of length of shop shears being about 12 in. to 16 in. When the edge of a plate has to be trimmed in an engineer's shop, it has to be done in detail, a few inches at a time, in the common shears—a laborious process. Moreover, such trimming of plates means a waste of material, paid for at the rate of several pounds sterling a ton, whereas at the rolling mills plates are cut and delivered of definite sizes without extra charge, extras of course excepted, and the shearings are balled up again without loss. Only when the shapes of plates are other than rectangular is cutting to size charged for.

Sketch Plates.—Plates other than rectangular come under the denomination of "sketches," or "sketch plates," charged for extra at the rate of about 20s. per ton. Some houses, however, will include a certain percentage of sketch plates in an order at usual prices—as many as 15 per cent.; and some include plates with not more than 3 in. of taper on the edges in the ordinary rates. But with these exceptions all tapers, curves, circles, and irregular forms are extras.

Sawing Angles, &c.—As regards the section irons and steels, these are rolled in certain lengths suitable to the different sections. And to cut angles, tees, channels, &c., in quantity with a hammer and sett, is a slow and costly business. For these reasons many engineers employ a cold iron saw—Hill's or Hetherington's—a machine which soon pays for itself, for it not only cuts with practically no waste—only the thickness of the saw, $\frac{3}{16}$ in.—but the cut ends are as true and smooth as though planed. Moreover, ends can be cut by it to a bevel as well as square.

Cutting Block.—Angles and tees, even though sawn originally with the hot or cold iron saws, have also frequently to be dressed off at the forge after the performance of various operations, as bending, setting down, or lining out. It is then often impracticable to use the saw for dressing off the ends, or it is not worth while going to the saw for the purpose. The

block shown in Fig. 84 is then generally utilised. It is a cast-iron block of about 16 in. square, and 7 in. or 8 in. thick, provided with grooves to receive one of the webs of angles and tees, the other web lying upon the top face (Fig. 85). The edges of the grooves are rounded to suit the radii in the throats of the angles, and sometimes also one or two outside curves are well rounded, as shown dotted, for the convenience of bending work round them. The block is generally made to fit one of the stands used for supporting templet and die blocks, which will be illustrated in a subsequent page. It is used for a multiplicity of purposes. Fig. 85 gives a perspective view of the block with a piece of tee iron, A, and a piece of angle iron, B, laid upon it in positions for cutting. While so lying, the web, which lies flat, is cut off with the hot sett, the cutting being done partly from one side, and then the angle or channel, being turned over, is finished from the other. The positions of the webs are then changed, the one which has been cut being dropped into the groove, while the other web is laid flat, and similarly cut.

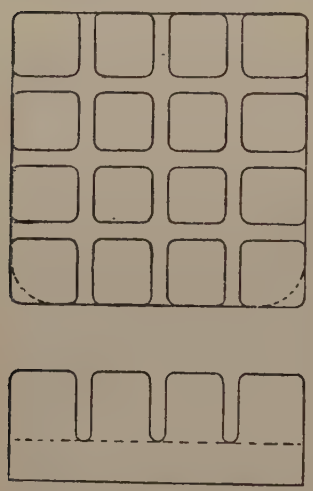


FIG. 84.

Planed Edges.—The edges of plates are always planed for the best work, not only to make good and neat joints in the best girder-work, but in the case of boilers, as a matter of safety. If the edge of a shorn plate is examined, it will be seen to present an innumerable array of incipient cracks, due to the violently detrusive action of the shears. Under the stresses of riveting, caulking, and steam pressure, some of these cracks would spread, and become a source of danger, leading to rupture. But if the edges are planed, all these tiny cracks are cut away, and the edges are left quite sound. Further, it is easier to caulk a planed edge securely than a roughly shorn

edge. The plates are either planed in a common planing machine or in one of special construction—the "plate-edge" or "open-side planing machine," designed exclusively for use in boiler shops—in which the tool travels and the work is stationary.

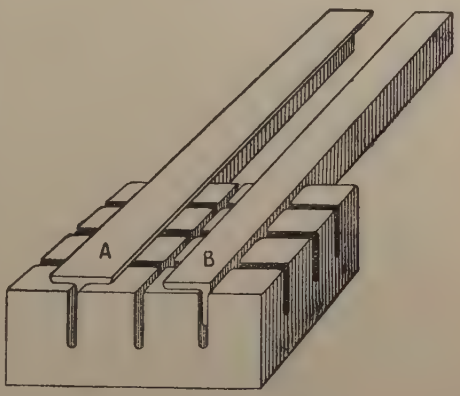


FIG. 85.

Fig. 86 illustrates a good type of plate-edge planing machine, made by Messrs Kendall & Gent Ltd. It planes from 15 ft. upwards, the beam being overhung so that plates of any length and breadth can be clamped on the table. The clamping screws are held on a steel beam over the table. The carriage is driven along by a large screw, turned in alternate directions by belt pulleys with open and crossed belts, connected either from a line shaft, or driven direct from a wide pulley on an electric motor, as seen in the present example. The carriage has two tool-boxes, with the tools set face to face, so avoiding the reversal of the box. The carriage itself actuates the belt-shifting forks, striking a rod with adjustable dogs which move the rod and ship the belts. For further remarks on planing machines, *see* Chap. XVII., p. 296.

Cutting Curved Edges.—There is only one way of cutting curved edges in the boiler-shop, and that is by drilling contiguous holes, and thus removing the bulk of the material, and finishing the edges by chipping. To give one example only, Fig. 86A shows a plate for the lower half of the shell of a common vertical boiler, prepared for bending. A is the fire hole, and B is the arch through which the ashes are raked out from under the fire-bars. C, C, are the mud-holes placed opposite the cross tubes, and D, D, D, are the mud-holes just above the foundation ring. These holes, by the way, are always outlined, and punched as shown, *before* the plates are bent; but the

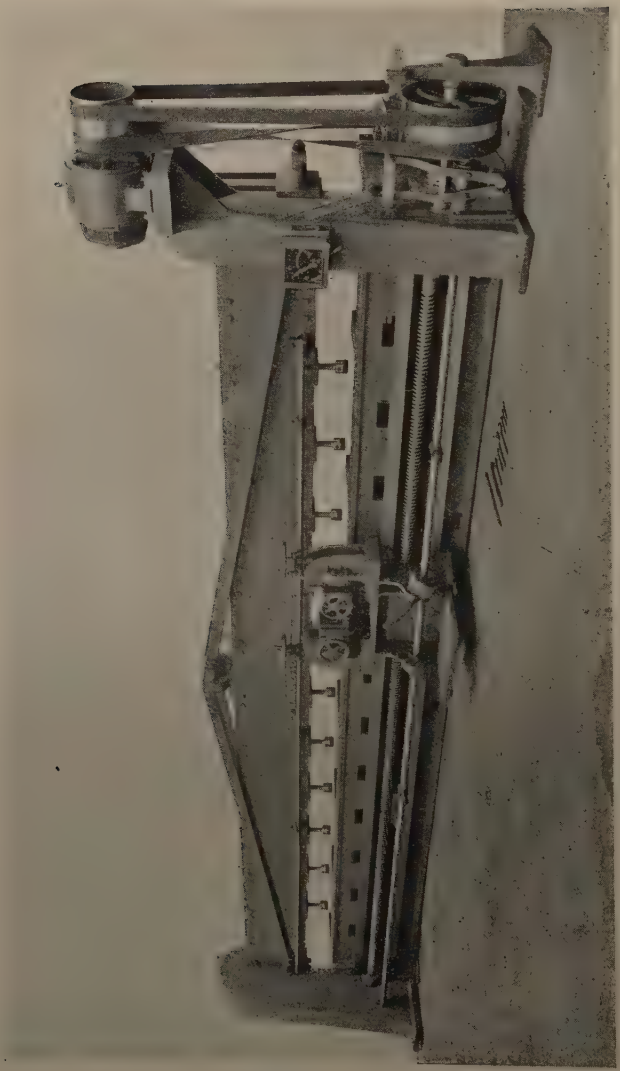


FIG. 86.

metal is not finally removed until *after* the bending is done, with the exception sometimes of the mud-holes, which, being of small area, are often punched clean out before bending, as

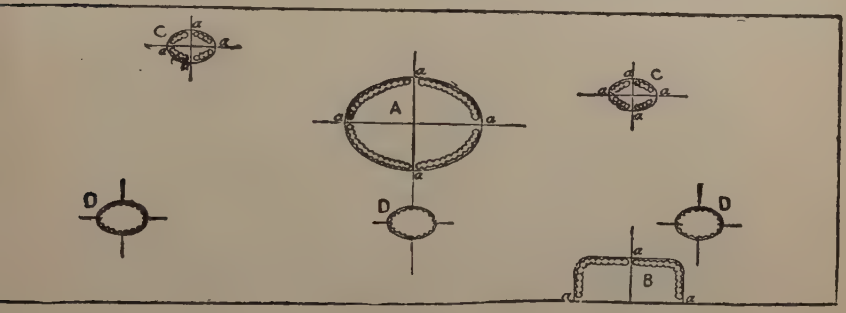


FIG. 86A.

shown at D. But the large openings always have the centre portion left intact, united by the narrow bridges of metal *a*. The continuity of the plate is thus left practically unimpaired, and, after bending, the connecting bridges of metal are drilled or chipped out, and the holes smoothed and finished by chipping. Most curved edges, whether quick or flat, are formed in this way by the punching of contiguous holes. The holes will be from $\frac{1}{2}$ in. to $\frac{3}{4}$ in. diameter. There are, of course, the exceptions of drilled holes, and the circular holes for flues, tubes, and tube stays. There are also machines made for punching manholes, &c., with dies, but their use is not very general yet. Ordinary drills are used for small holes; but for the larger holes for tubes the drill shown in Fig. 87 is

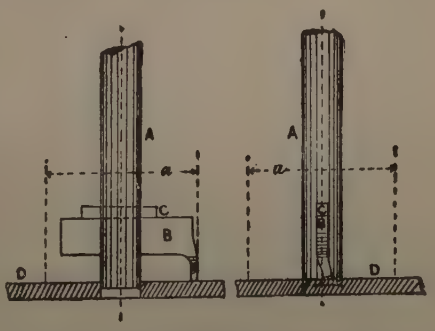


FIG. 87.

employed. It consists of a shank, A, cutter, B, and wedge, C. A hole is first drilled in the plate D, of the same diameter as the shank of the drill, and this serves to steady the shank during the stress of drilling. The cutting-edge has no front rake, which would cause chattering, and it is placed about in line with the centre of the shank—not in front of it. The tool removes an annular ring of metal of the diameter *a*.

All materials which are worked into structures have to be either straightened or bent. There is never a true plate, angle, tee, or channel brought into a shop, and nothing that is not first made true, and correctly shaped, as required for its purpose, should ever be worked up into a structure, because an inaccurate plate or section-bar will pull adjoining parts out of truth. Hence, a large portion of the skill of the plater and boiler-maker consists in straightening and bending correctly the materials brought into the shop. We will therefore consider these important matters in some detail.

Levelling Blocks.—The levelling of thick plates is done in two ways: either upon a levelling block or between straightening rolls. The first is very common; the second is the better method.

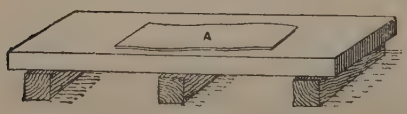


FIG. 88.

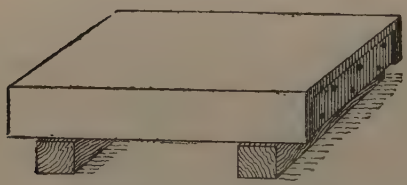


FIG. 89.

Levelling blocks are shown in Figs. 88, 89. They consist of a plain solid slab of cast-iron, Fig. 88, planed over on the top face, and supported on wooden blocking; or of a ribbed cast iron block, Fig. 89, either laid on the floor or supported on wooden blocking. Dimensions will depend on the class of work chiefly done. For general use a block such as Fig. 88 may measure from 10 ft. to 14 ft. in length, and from 4 ft. to 6 ft. in width. A solid block like

this should not be less than 5 in. or 6 in. thick, and a ribbed block like Fig. 89 should not be less than 12 in. or 14 in. entire depth ; but then the thickness of the plate need not exceed from 3 to $3\frac{1}{2}$ in., being stiffened with ribs underneath. These blocks are made so thick not so much to lessen risk of fracture, which seldom happens, but in order that they shall retain truth of surface. It is a fact that these blocks, notwithstanding their great thickness, lose their accuracy in time, becoming *convex* on the top face, due to the incessant hammering which they endure. If they are not level, of course it is difficult to level plates upon them, so that it is necessary, after an interval of a few years, to plane the top face over to restore its original accuracy.

Sometimes excessively long plates, flats, angles, tees, or channels have to be levelled ; or it is convenient to use the block to put long slender work together upon. For these reasons it is desirable to have more than one block. Then it is convenient to make two or more blocks of the same width and thickness, even though not necessarily of the same length, and either block them up level, end to end, or, in the case of Fig. 89, bolt them together in addition.

Straightening Plates with the Hammer—Details of the Process.—Straightening plates with the hammer is not a method to be commended, yet a great deal of it is done in boiler shops, for the simple reason that very many shops are not furnished with any straightening rolls. A good deal may be done with the common bending rolls to take the worst of the buckles and kinks out of plates, in the way to be noted presently ; but even then final corrections have to be given with the hammer.

The objections to straightening plates with the hammer are, the unsightly bruises inflicted on the surface, and which, even in the hands of a careful man, are not entirely avoidable ; and worse still, the local stressing to which the plate is subjected by the hammer blows rained on its surface. Under every blow, a minute area of the plate is subjected to minute vertical compression and lateral extension, so that a hammered plate is dotted with a large number of centres of local stress and local hardening, with surrounding zones of homogeneous metal. Then there is the vibration set up in the material, which tends to develop or favour a condition of crystallisation, and so induce incipient fatigue—in fact, inferior plates will sometimes crack during the straightening process—an indication of the rough

nature of the treatment endured even by good plates. If the plates were straightened with wooden mallets while red-hot, of course the objections just named would not exist. But then it is impracticable to straighten any except the smallest pieces of plate while hot, for the reason that they would buckle again as they cooled, so that, excepting in the case of small pieces of plate, all straightening has to be done cold.

When a plate is straightened in the rolls, there is, of course, neither local hardening nor hammer marks; but the buckles are taken out by gradual extension of the plate by means of forces acting uniformly over a broad area. And though the process is conducted cold, there is no undue stressing of the plates, because, as we have seen in connection with tests, even common plates will stand a good deal of doubling up cold without suffering injury. For these reasons, passing plates through the rolls is the ideal method of straightening, and hammering is to be deprecated. But since there is probably as much or more hammering done than rolling, we must needs give some consideration to each method.

When an elastic plate is concave on one side and convex on the other (Fig. 90), the reason is that it is shorter on the concave side A, than it is on the convex side B. To hammer such a plate straight, the side A must be extended by hammer blows until it is brought to the same length as B. Each hammer blow has the effect of slightly extending or spreading a local disc of metal, and as these merge into one another over the whole surface of the plate, the effect is the gradual extension of the whole surface A. Hence it is the concave side, and not the convex side, of a plate that must be hammered in order to bring it level.

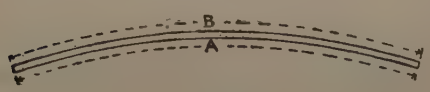


FIG. 90.

Another point is that the blows must be opposed to a solid unyielding surface underneath. If there is a hollow space underneath, as in the case of an uneven surface, vibration will be set up, and the plate will spring under the hammer, and the metal will not be extended, but bent.

There are two general conditions that may exist in buckled plates, one in which the central portions are bent, being held by the more rigid bounding edges; the other in which the

central portions are tight, the bounding edges being loose. Besides this, local kinks will occur along the edges. In the first instance, the bordering edges of the plate will have to be extended by hammering; in the second, the central portions must be hammered.

Taking the first instance, that of a depression somewhere about the central portion of the plate, no amount of hammering on either side of that depression would remove it. Hammering might send it from one face to the other, but would not remove it. The buckle is held fast by the bordering metal, and the only way to remove it is to stretch the metal by which it is bound and prevented from extending. So that the aim is to hammer, not on the buckle, but over all the surrounding metal, until that is stretched sufficiently to permit of the buckle extending into a true plane. The blows must be given with regularity, beginning at the margins of the plate and working inwards. Regularity is necessary in order to avoid the risk of creating new errors in other portions of the plate. Contrariwise, to remove buckles about the margins, the central parts of the plate must be stretched by hammering until the tense parts are extended into the loose portions. In the case of a buckle near an edge, the metal immediately adjacent is hammered. It is easy to exceed the amount of stretch required, and so set up fresh buckles in the plate, in which case much, if not the whole, of the work may have to be gone over again. For a true plane is very difficult to get, and a little extra tension in one section will suffice to cause distortion. For this reason thin plates are more difficult to level than thicker ones, as witness the case of a buckled circular saw.

In levelling the thick plates of the boiler-shop, invariably the flat face of the hammer is used; never, as is frequently the case in thin sheets, the cross pane. Levelling with the narrow pane of a hammer would bruise boiler-plates too much. When straightening plates with the hammer, the legitimate hammer-marks are of course unavoidable. But the evil to be avoided is indenting of the surface with the edges of the hammer, due to the hammer not being brought down level upon the surface. Nothing looks much more unsightly in plated work than these hammer-marks, especially on the shell of a boiler.

An iron straight-edge is the test employed in levelling plates. On first laying a plate upon the levelling block, when it may perhaps be as uneven as that shown at A in Fig. 88, it is scarcely

necessary to use the straight-edge, the eye being sufficient judge of the condition of the plate; but when the plate is brought fairly level, then the straight-edge, being tried upon it lengthwise, crosswise, and diagonally, indicates the ridges and depressions. The plater directs the blows of his strikers by striking with his own hammer—usually a light one—upon the required area, the strikers following with their hammers upon the same spots, following over the plate in unison with his hammer. The straight-edge is tried again at intervals, the plater noting every little item of importance, observing, too, the light reflections, the ring of the plate, and indications of tension or looseness.

Straightening in Rolls.—The work of hammering is often greatly reduced, and for many kinds of work avoided altogether, by first passing a plate through the bending rolls, whereby the long easy curves and the buckles are largely obliterated. This effects a considerable saving of time in the case of large plates, besides lessening the total quantity of injurious hammering. And in the case of plates that have to be only brought fairly level for lining out preparatory to subsequent bending, no hammering at all would be necessary in the case of these. The method is this. The plate is supported at one end by labourers, or if of large size by means of the slinging hooks (Fig. 91), and entered within the rolls, the top roll being so adjusted that the passing of the plate between the upper and lower rolls shall just suffice to impart a slight *curvature* or "camber" to the plate. The plate is then turned upside down and run back through the rolls, and a slight curvature, about like that shown in Fig. 90, in the opposite direction imparted to it. Then it will be run to and fro several times, the position of the rolls being so adjusted until finally the curvature is all removed, and a fairly flat surface results. If the plate is small, it will be run right through by hand, each time; if of considerable length, it will be run to and fro for, say, two-thirds or three-fourths of its length, the direction of rotation of the rolls being reversed, and the plate supported in the slings from the jib of a pivoting wall-crane; and when that portion of the plate is completed, the

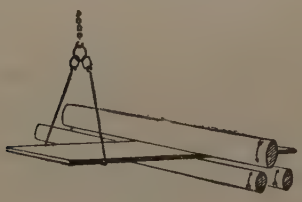


Fig. 91.

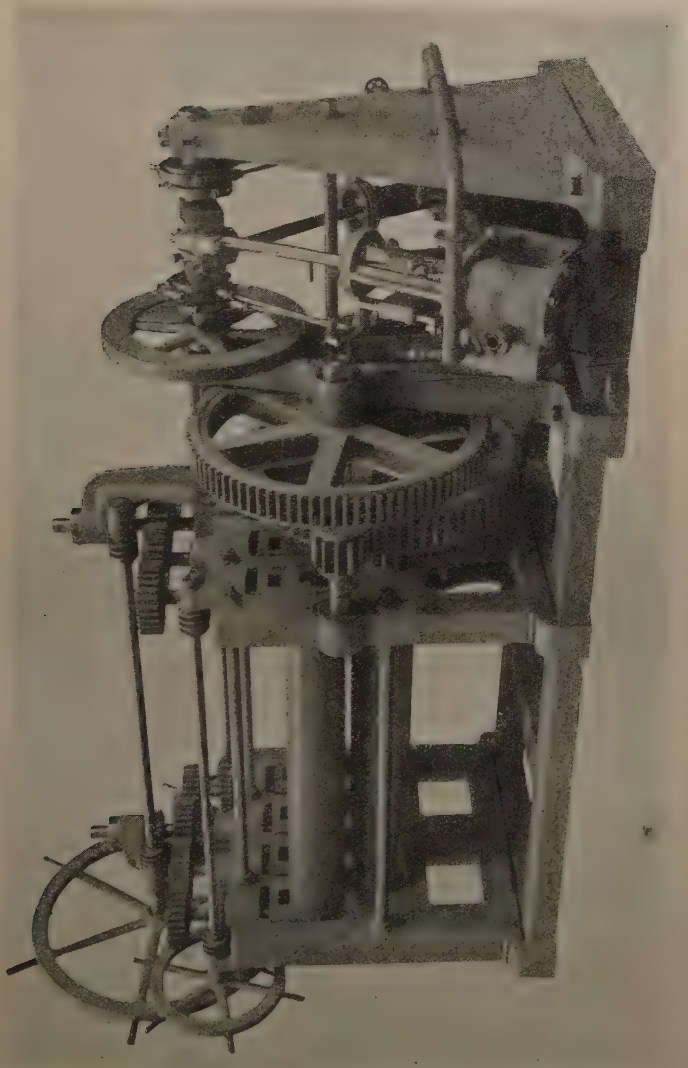


FIG. 92.

plate will be reversed end for end in the slings, and the other end finished in like manner. In Fig. 91 it will be understood that the bare rolls only are shown, without housings, journals, or driving and reversing gear.

The straightening of plates in the straightening rolls or "mangle," as the machine is termed by some boiler-makers, is done by passing them between a succession of rolls. There are usually seven rolls—four above and three below. A very crooked plate is thus straightened in one, two, or three passes. Two will suffice, but for the best work, three are better. In one pass the plate is cambered in one direction, in the next it is cambered in the opposite direction, the two operations removing all buckle. A third pass straightens the plate.

Fig. 92 shows a flattening or straightening machine, manufactured by Messrs Francis Berry & Sons. It will straighten plates up to 6 ft. 3 in. wide, by $\frac{11}{16}$ in. thick. The seven rollers are $14\frac{1}{4}$ in. diameter; four of them can be raised or lowered simultaneously, or if necessary the two outer rollers can be moved separately. The mechanism, including handles, worm gear, and screws for elevating, is seen clearly in the view. A double cylinder inclined engine is employed for driving, through double shrouded gears, which connect to the cast-steel pinions keyed on the three driving rollers.

Straightening Section Irons — Details. — Section irons are straightened upon a block like that in Fig. 93, or in a special squeezing machine or straightening press. The lighter sections are generally done upon the block; the heavier in the machine. The method of straightening sections is quite different from that of plates. There is no stretching and extending of surfaces in the former, but *setting* and bending only. Thus, for instance, if the angle-iron ring in Fig. 94 were found on measurement before welding up to have been bent up in the first place to too large a circumference, its circumference would be reduced by setting and reducing the

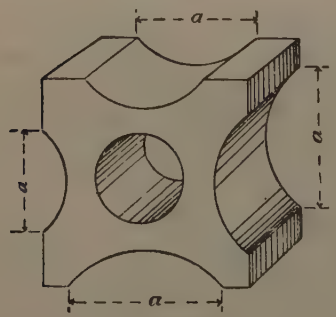


FIG. 93.

inner circumference with hammer blows, the process being that of *bending* simply. The ring would be laid upon a block and blows struck in detail all round the inner edge. Two strikers would each hold a sledge at, we suppose, A A, and the smith would strike blows horizontally against the edge at positions between A A, as at B B B, with the effect of *quickening* the curvature in that locality, as shown by dotted lines exaggerated. The repetition of the process in detail all round the ring would reduce the circumference. It will be seen that the length between A and A is subject to bending; the hammers held at A A, being of the nature of solid supports, so that the ring can only yield by bending to the forces imposed by the hammer blows at B B B.

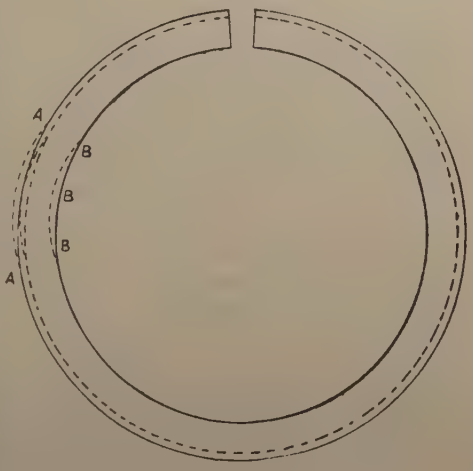


FIG. 94.

Precisely the same essential method is adopted in all straightening of section irons and steels, whether it be done on a block like Fig. 93, or in a straightening press; the straightening takes place between two rigid points of support.

The block, Fig. 93, is of cast-iron, and may be from 12 in. to 16 or 18 in. square. It will be noted that the distances *a* between the supporting edges are different on each side, so that in a single block four different lengths of support and of leverage are obtainable, thus rendering it available for use with light and heavy sections, requiring less and greater leverage respectively. The radii included between the points of support are of no moment at all, so long as there is a concavity of some kind between the supporting faces. Neither is the central hole of any account. It is simply a lightening hole lessening the

weight of the block, which has to be lifted mostly by hand. The block is usually supported on a cast-iron stand like Fig. 95, an appliance useful for supporting other blocks besides, the blocks resting upon the ledges *a*. Fig. 96 shows the block in its stand, and a piece of angle resting upon it in position for being straightened. In this figure, *a a* are the points of support and reaction, corresponding with A A in Fig. 94, and hammer-blows delivered at *b*, where there is convexity, remove that convexity and straighten the angle. A couple of labourers, one at each end of the angle, move it about on the block endwise, and from one face of the angle to the other as required, acting under the direction of the smith, who judges

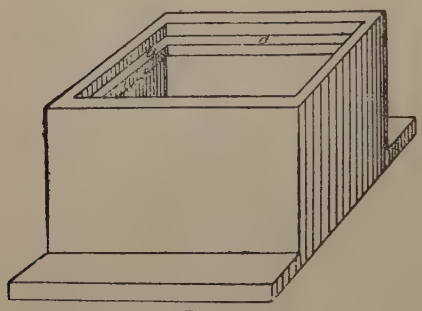


FIG. 95.

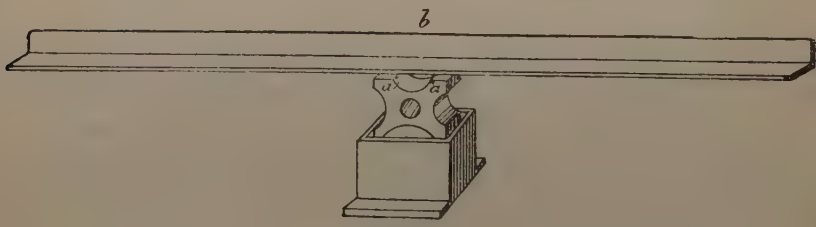


FIG. 96.

of the amount and location of correction necessary by sighting along the angle endwise, just as one judges of the truth of an edge or surface by looking down or along it from one end, with the eye on a level with it. Not only the edges, but the flat faces also, will have to be corrected; but this is done with the hammer entirely, not with the flatter at all, at least not on this block. Sometimes the flatter is used for final correction, the angle being taken to the levelling block for the purpose. Of

course, all this straightening that I am speaking of is done cold.

Straightening Machine. — It would be exceedingly laborious to try to straighten the heavier sections of any kind in this manner. Hence, all shops of any considerable size use a "straightening machine" or "squeezer" for channels, joists, and the heavier angles, tees, &c. The machine is too elaborate for me to illustrate its details properly here; but the diagram, Fig. 97, and illustrations Figs. 98, 99, will illustrate sufficiently well for our purpose the method in which it oper-

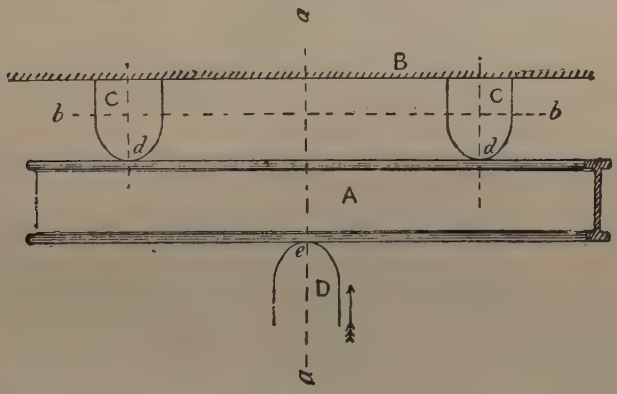


FIG. 97.

ates upon the section-iron. In the diagram. Fig. 97, let A represent a joist which has to be straightened. Towards one end of the machine there is a cross-slide, represented diagrammatically by B, and capable of considerable movement by means of a screw or other device in the direction of the line *a a*. Two blocks, C C, 15 in. or 18 in. in depth, are fitted to the face of the slide, and can be traversed along its face, either towards or from the centre, along the line *b b*. D is a ram or squeezer attached to the other end of the machine, and movable along the line *a a* by means of gearing and eccentric shaft in some machines, as in Fig. 99; in that illustrated in Fig. 98, by hydraulic pressure. The ram can be thrown out of gear or into gear at once, similar to a punching machine. The acting faces of the blocks, C C D, are rounded as shown; *d d* are the

FIG. 98.

fixed points of support to the joist, corresponding with A A in Fig. 94; and the point *e* is that at which the squeezing force is applied in the direction of the arrow. As the blocks C C are movable nearer to, or farther away, from *a a*, the points of leverage, *d d*, are alterable to suit the various irregularities in the sections which have to be straightened. Fig. 98 illustrates a machine of this type actuated by hydraulic power; Fig. 99 one by belt power with double gearing. The latter is made by A. & P. W. M'Onie, and will operate on beams up to 12 in. deep. Of course, in both classes of machine the operations of bending as well as of straightening are done, and done much more efficiently than they can be accomplished by means of hammers and mallets. The bending is done gently, and its amount depends on the amount of pressure and movement imparted to the ram relatively to the resisting blocks.

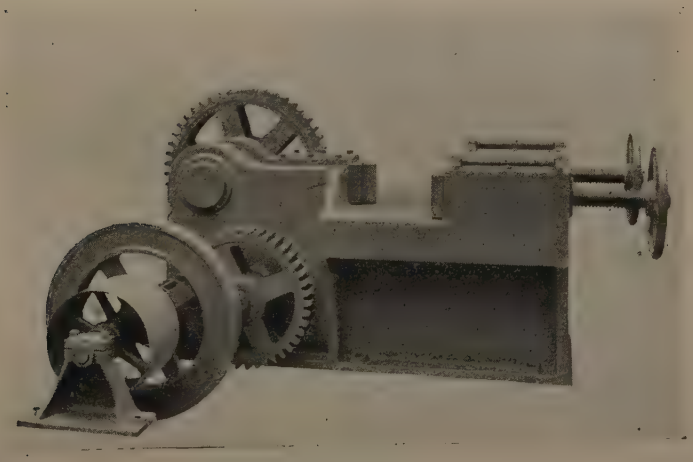


FIG. 99.

CHAPTER VII.

BENDING PLATES.

The Reverberatory Furnace—The Bending Rolls—their method of action—their essential imperfections.—Descriptions of their Gearing.—Bending Rings.—Bending Conical Forms—Bending Sections of Plates.—Bending Envelopes of Spheres—the use of templets.—Bending Blocks—various types.

The Reverberatory Furnace—The bending of plates is done both hot and cold. When plates are bent to a regular curve, they are done cold; if they are dished or flanged, they are done hot. Section-irons and steels are almost invariably bent hot, the exceptions being sometimes when their curvatures are very slight or "flat." Bending-rolls, templet-blocks, and presses are the appliances made use of for bending and flanging. For heating plates and section-irons of considerable length and area, the reverberatory furnace is used. For short heats the forge fire is employed. The advantages of the reverberatory or plate furnace are that large areas and lengths can be heated at once, and uniformly, and that the fuel does not come into contact with the metal at all. The accompanying drawings illustrate a good reverberatory furnace for general purposes in use in boiler shops. Sizes will vary, of course, according to the average run of work, but the drawings gave proportional relationships.

Fig. 100 is an external elevation of the furnace; Fig. 101, a plan view, also of the exterior; Fig. 102, a front view looking against the working door; Fig. 103, a longitudinal sectional elevation taken down to the centre of the furnace; Fig. 104, a sectional plan taken on the furnace hearth; and Fig. 105, a transverse section on the hearth. The furnace is built of firebrick, A, well bound together at sides and ends. Along the sides there are long washer-like ribbed iron castings, B B, &c., extending from

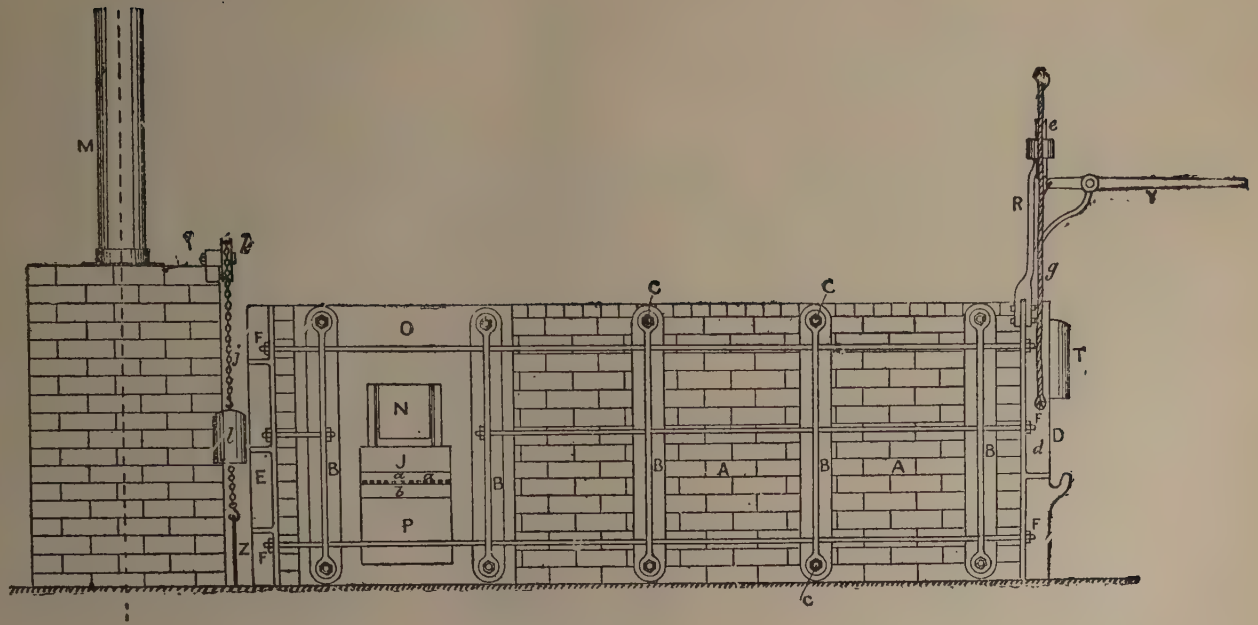


FIG 100.

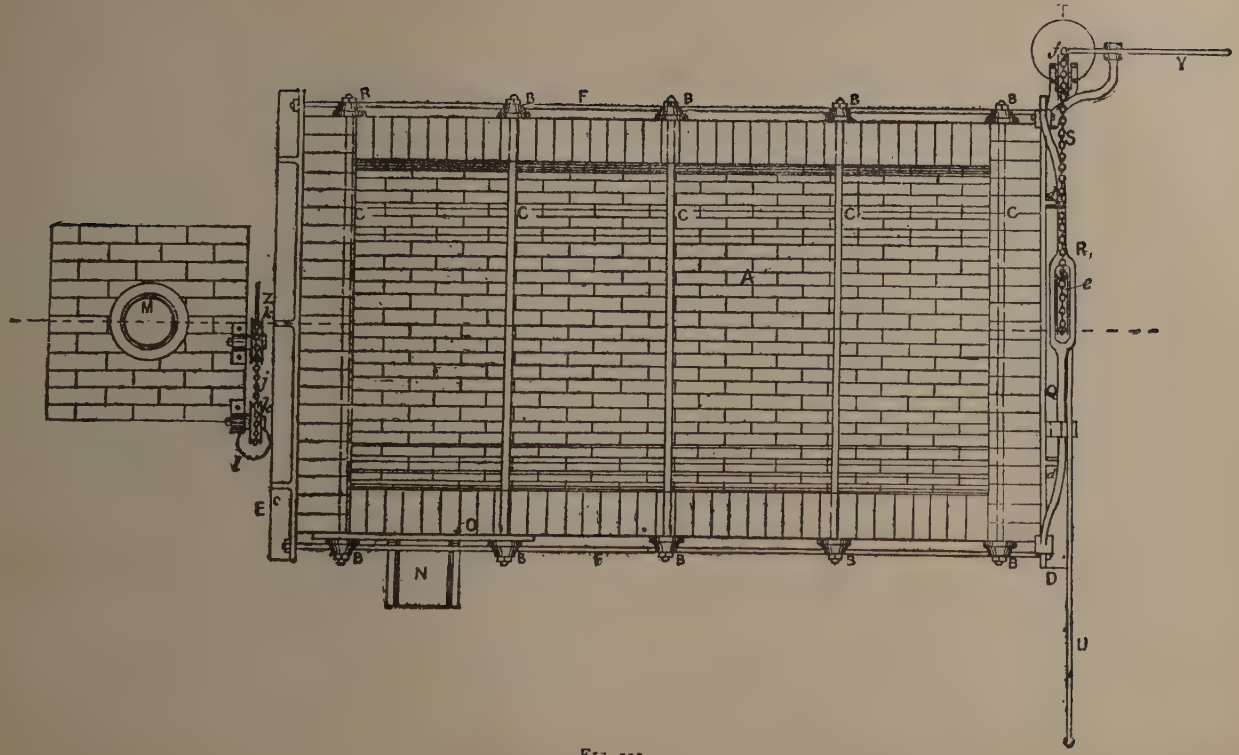


FIG. 101.

top to bottom, and tied to each other against the furnace sides with stout bolts, C C. The furnace ends are tied with large cast-iron plates, D, E, well stiffened with deep ribs, and held against the brickwork with long tie-bolts, F. Holes are cast in the washers B to permit of the passage of these bolts. G is the bed of the furnace upon which the work is laid to be heated. The crown of the furnace is well arched, the roof being built strongly, as shown in section in Fig. 105. At the farther end of the furnace the bridge H separates the fire-grate J from the furnace-bed G, and the roof over the fire-grate is arched in such

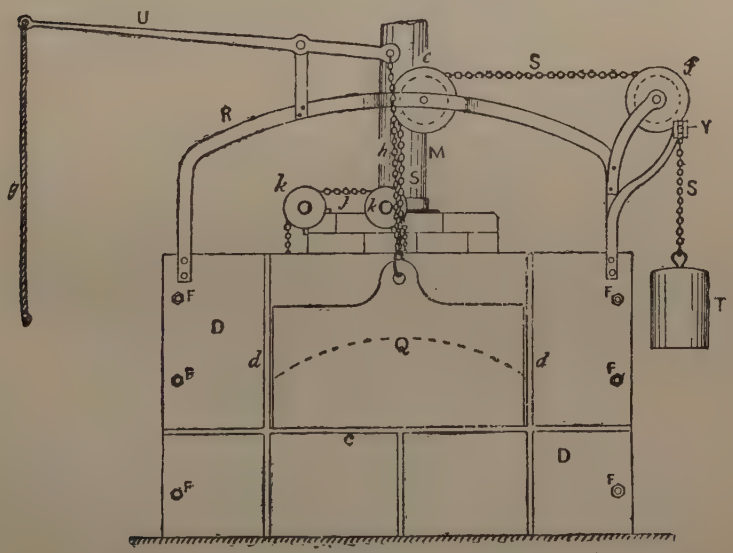
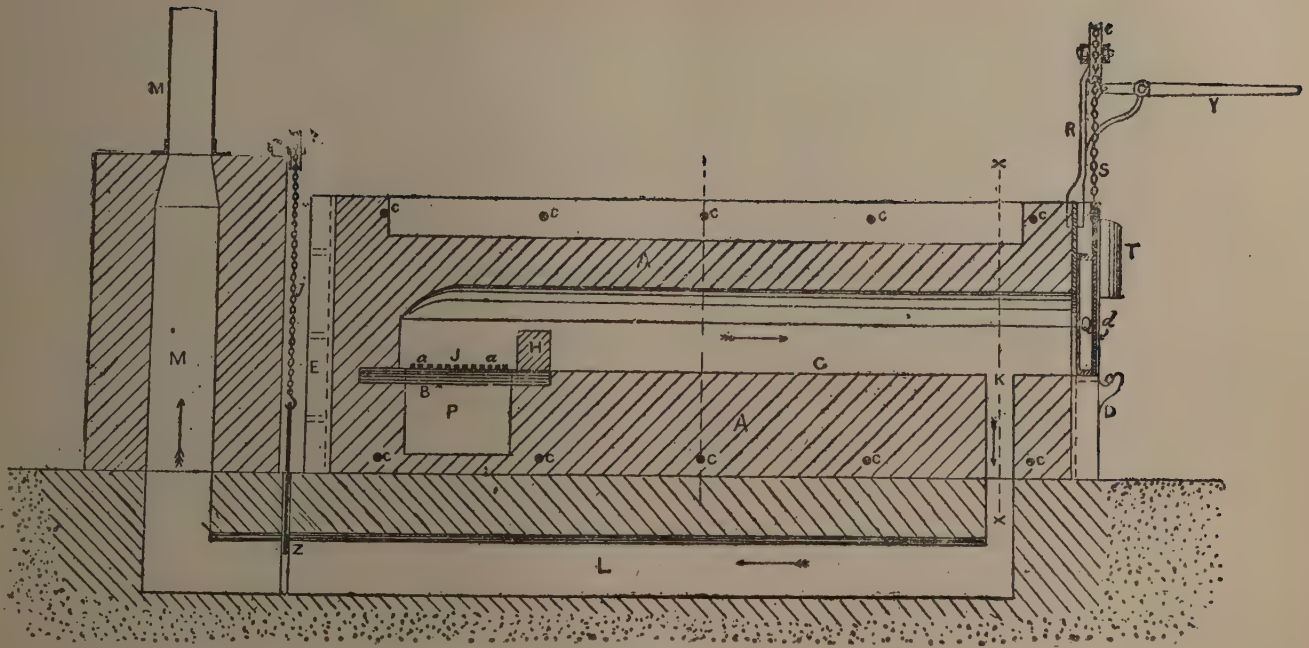


FIG. 102

a manner over the fire-grate J, Fig. 103, as to throw or deflect the flame and heat towards and over the bridge H into the body of the furnace, whence it is deflected by the arched roof in its passage upon the work which lies upon the bed. Such heat and flame as reaches the front end of the furnace is drawn down into the three openings K K K, Figs. 103-105, and thence through the culvert L into the chimney M, the draught from which induces the heat and flame along the furnace. Little or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M
E
C
C
C

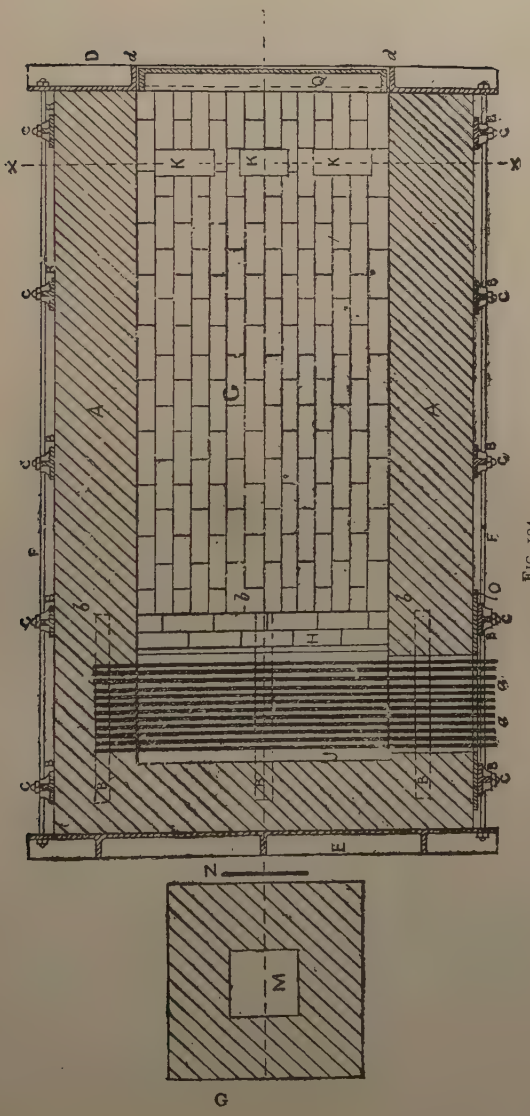


FIG. 104.

no smoke escapes from the furnace after it is thoroughly hot the intense heat consuming the smoke.

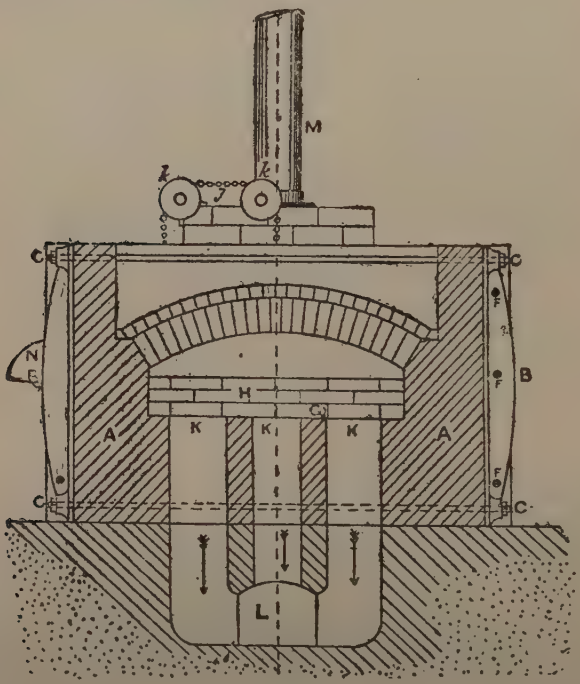


FIG. 105.

The fire-bars *a a* of the grate area are of wrought-iron; the bars rest upon stout wrought-iron bearers *b b* built into the brickwork. The fuel used is small coal, fed in through the sheet iron hopper N. A cast-iron plate O is fastened to the furnace side at this locality, and the hopper is attached to it with angle-iron. The coal is caked on the hopper before it is pushed into the furnace. The hopper is filled right up with green coal, so closing the furnace mouth, and when the coal cakes it is thrust in, the bottom of the hopper being sloped slightly towards the furnace, and fresh coal is then shovelled into the hopper. The ashes are raked out into the ashpit P.

The front plate D of the furnace is provided with an opening or doorway for putting in and withdrawing the work through. One of the ribs forms a ledge *c*, Fig. 103, which protects the edges of the front bricks from injury. The opening is closed with a sliding door Q, sliding between the vertical ribs *d*, and provided with chains, levers, and counterweight. There is an arch R of wrought-iron bar, bolted to the plate D. This carries in a recess a grooved pulley *e*, and at the end of a bracket another grooved pulley *f*. The chain S, attached to a lug on the working door Q, passes up and over both pulleys, and is attached to the counterbalance weight T at the other end. The door is lifted with the lever U, pivoted in a bracket bolted to the arch R. A rope *g* is attached to the long arm, and a chain *h* to the short arm, the chain being fastened to the working door to the same lug as the chain S. To close the door, which, being exactly counterbalanced, will not close by its own weight, a lever Y is employed, also pivoted in a bracket bolted to the arch R. The short arm of this lever is linked to the chain S, and so moves it upwards, and closes the door.

A damper is fitted to the furnace for regulation of the draught. It consists of a plate of cast or wrought iron Z, sliding in grooves cut in the sides and roof of the flue, and adjusted by means of the chain *j* passing over the pulleys *k k*, running in bearings fixed to the chimney-stack. The damper is counterbalanced by the weight *l*.

When, as sometimes happens, a piece of section-iron longer than the bed of the furnace has to be heated, then it must be done in two heats, one end first, the other afterwards. Since the door of the furnace cannot be closed completely with the section-iron lying partly outside the opening left between the bottom edge of the door which rests on the section-iron and the bed of the furnace, it is covered up with a piece of plate, and luted with small coal. The only part of the doorway left open then is that which is partly occupied with the section-iron.

The Bending Rolls.—There are many types of plate-bending rolls, into the separate details of which it is not within the scope of this volume to enter. I can only deal with some of their cardinal features. Vertical rolls are used to a moderate extent, but the horizontal are the ones in most general service. For boiler shops they range from about 7 ft. in length to 30 ft. or more. They are driven by gearing fitted with reversing apparatus. The reversing gear usually consists of an open and

a crossed belt driving on two sets of fast pulleys, similarly to a plate-edge planing machine.

Fig. 106 will give an idea of the general appearance of horizontal bending rolls. These are built by Messrs Fairbairn Macpherson of Leeds, and are constructed to take plates 9 ft. wide by $\frac{3}{4}$ in. thick. Open and crossed belts on the loose pulleys drive to the central fast pulley alternately, for forward and reverse motions, and double gears transmit the power to the two lower rolls. Angles and tees can be bent by the small rolls outside the left-hand cheek, which is made to swivel for effecting the removal of complete rings from the top roll. Vertical rolls are in general use for heavy work. They are usually driven by independent engines. The plates are more easily handled in vertical than in horizontal rolls. No matter what their curvature, they can be easily taken away, whereas in horizontal rolls curved plates must curve upwards or downwards as they leave, which often makes handling and slinging awkward. When rolling circles, the front roll is removable. Machines are triple-geared, and have two variations of speeds to suit the working of light or heavy plates. In these machines the rollers are made of forged steel.

Some of the largest plate-bending rolls yet made have been constructed by Messrs T. Shanks & Sons, of Johnstone, N.B. These will bend plates up to 36 ft. long, by $1\frac{1}{4}$ in. thick. The top roller, of forged steel, is 30 in. in diameter. The under rollers are 17 in. in diameter. The driving motion is provided with double gear for heavy plates, but single gear is used for light plates. Examples of large rolls are given on pp. 299, 300.

Many of the more powerful plate-bending rolls, in common with other boiler-shop machines, are now driven by independent engines or electric motors, instead of from line-shafting. In some respects this is advantageous, as follows:— It is cheaper to bring a steam-pipe or cable to a machine than to bring line-shafting and belting to it. If there is line-shafting in a shop, the machines must be arranged in close proximity to that shafting, whereas independent machines can be set down anywhere, as happens to be most conveniently situated for the execution of the work. Many machines are not in constant use, but are only wanted at intervals, and for comparatively short spells of work. The constant wear and tear

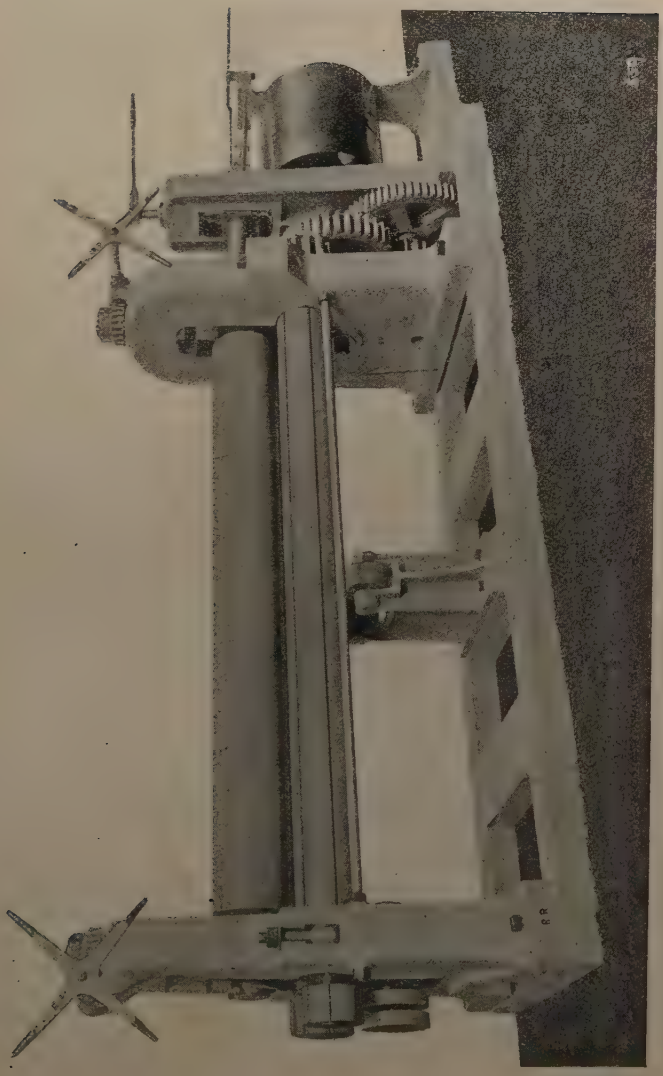


FIG. 106

and attendance on shafting is saved by the use of an independent engine, used only when occasion requires. Speeds can be varied to suit work with independent engines better than with shafts and countershafts.

Method of Action.—The essential action of bending rolls is shown in the sectional diagram, Fig. 107. There are two bottom rolls A A, to which rotation is imparted by gearing in various ways, the rotation taking place in the same direction as indicated by the arrows. Sometimes a horizontal shaft runs underneath the rolls, geared from the pulley shaft, and carries a pinion at each end, each gearing with a wheel on one end of a roll. The wheels being at opposite ends of the machine, do not interfere with each other, and the rolls are driven in the same direction. These rolls run in fixed bearings, so that the positions of their centres *a a* are constant. There is a top roll B, which revolves in movable bearings, which is not actuated by any gearing, but only by its frictional contact with the plate C, which is being bent. Since the centre *b* of the top roll B is not fixed, it is therefore capable of movement upwards or downwards, and it is by means of this capacity that plates are bent to different curvatures in the same rolls. Thus, in Fig. 107 the relative position of B to A A is such that a very flat curvature is being imparted to the plate C, while in Fig. 108 the centres of B are approached so much more closely to those of A A as to im-

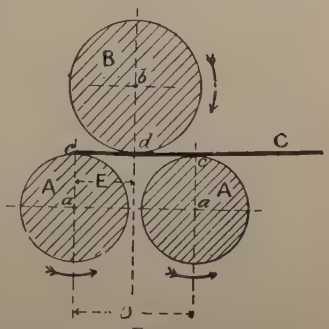


FIG. 107.

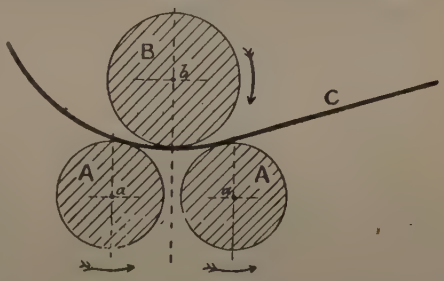


FIG. 108.

part a very quick curvature to the plate C. By raising or lowering the centre *b*, therefore, of the top roll B, plates are rolled flatter and quicker respectively. The attendant judges by his experienced eye of the amount of vertical setting required to impart a given amount of curvature to a plate, assisted by the employment of a templet by which to check the curvature, and adjusts and readjusts its height while the rolling is being proceeded with.

The height of the top roll is adjusted either with a screw and lever, or with a special worm operated by power. The former method is only adopted in the case of the smaller machines, say with rolls of about 12 in. diameter and 10 ft. or 12 ft. long; the latter is adopted in the heavier machines. The bearings of the top roll slide bodily up and down in the end standards or "housings" of the machine.

To bend regular curves, meaning by that curves whose radii are uniform along the entire length of a plate, it is necessary to maintain the positions of the top and bottom rolls at a parallel distance apart. If the top roll is permitted to stand higher at one end than at the other, the curvature of the plate will not be uniform from end to end; but it will be flatter at the end where the roll is highest, and quicker where the roll is lowest. And if the plate is rolled thus into a complete circle, the resulting form will not be that of a cylinder, but of a frustum of a cone, and this is the way in which conical forms of varying radii and curves are rolled: by raising the top roll higher at one end than at the other, and the amount of coning, or the difference in curvature will be greater, the greater the departure from parallelism between the top and the bottom rolls (see Fig. 109), which shows in front view the departure from parallelism of the rolls A and B.

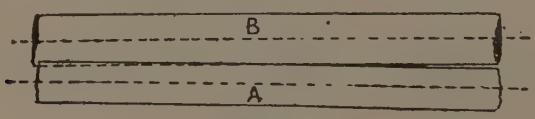


FIG. 109.

Various devices have been adopted to preserve a true bearing between the journals of the top rolls and its brasses when angled for bending plates of unequal curvature. In many of the smaller machines there is no special provision beyond a loose fitting of the block which carries the brasses of the top

roll in the housings. In other cases globular bearings, something like those used on some types of high-speed shafting, have been used. These devices, however, hardly concern us, the important point in this connection being the effect which the angling of the top roll has upon the coning of a plate.

Imperfections.—There are two evils inseparable from bending rolls—evils which cannot be eliminated, because inherent in the construction of the mechanism. One is due to the setting apart of the centres of the bottom rolls, the other to the elasticity of all the rolls. By reason of the first it is impossible to roll a plate into an absolute and perfect circle; because of the second it is difficult to give precisely the same curvature to the central portions of a plate as that which is imparted to the ends. The reason of the first is obvious on a glance at Fig. 107. The distance D between the centres *a a* of the bottom rolls A A, is fixed by practical considerations. The crowns *c c* of the rolls are the points of support or fulcra which resist the pressure of the top roll B acting at *d*. In every rolled plate there is an entering and a leaving edge, of width E, equal to half the distance D, which is not curved at all, but is quite flat, for the simple reason that no pressure is exerted on the width E, the pressure of the top roll not commencing to operate until the end of the plate has reached and rested on the crown *c* of the roll. This is a matter of less moment in the case of thin plates than in that of thick ones, and in plates of flat than in those of quick curvature. Moreover, the thicker the plates, the greater is the amount of flat on the entering and leaving edges, because they have to be bent in heavy rolls, and the heavier the rolls the greater is the distance between the centres of the bottom rolls. It is not practicable to obviate this evil by bringing the centres closer together, because by shortening the distance E, Fig. 107, the amount of leverage is lessened, and the power necessary to operate the upper roll and to bend the plate is correspondingly increased, and nearly all bending rolls as now constructed suffer to a greater or less extent from elasticity. The methods of forming the curvature of the last three or four inches of the edges of plates left flat by the rolls are as follows:—Sometimes, but this is bad practice, the plates are left to be pulled to curvature by the operation of riveting. Another bad practice is to use heaters to facilitate the work of bending. The best methods are either to heat the edges to a red heat and bend them with hammers over one of

the rolls or over a templet block before bending the plate itself; or to cut off the edges left flat from the rolls, and use them for butt straps or other work.

We now come to the consideration of the second point just now noted—namely, *the elasticity of the rolls.* Although the rolls of heavy machines are made correspondingly heavy, yet they spring in consequence of the enormous stress of rolling the massive plates required in modern structures. One result of the development of the steel industry has been, as we noted in a previous chapter, a great increase in the areas of plates rolled, so that it is not unusual for the plater to have to bend plates of from 20 ft. or more in length, and from 1 in. to $1\frac{1}{4}$ in. thick. Bending such plates cold means enormous machine stresses, and large and rigid though the rolls are, they yield and spring away from the plate about their central portions. The result is that the central portions of the plate would not be bent to the same curvature as the end portions, unless some dodging were resorted to. Sometimes, therefore, liners are inserted between the top roll and the plate about the central portions. Or in some modern machines the top roll is turned bellied, being made larger in the middle to compensate for the springing upward of the roll. An average, of course, has to be struck, because the amount of spring must needs vary in the case of plates of different thicknesses. In the largest rolls it may average a half-inch of rise, which means an inch of diameter more in the middle than at the ends. The bottom rolls when of great length are usually supported by small friction rollers, which also serve to relieve their bearings of some of the stress. The proportions between the sizes of rolls are about those drawn in Fig. 107. If the top roll were 12 in., the lower ones would be about 9 in. or 10 in., and so on.

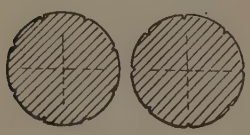


Fig. 110.

The frictional contact of the surfaces of the rolls with the surfaces of the plate is mostly sufficient to carry the plate through. But in the case of heavy rolls used for bending thick plates it is sometimes the practice to cut a few grooves in the bottom rolls, to enable them to bite the plate better, and lessen the chance of slip occurring. The grooves are not numerous, but as shown in Fig. 110.

Descriptions of Gearing.—Except for very light work,

belt-driving direct alone would not suffice for operating bending rolls, any more than single gear would suffice for heavy turning or machine work. As examples of the way in which power is gained, and the bottom rolls made to run in the same directions, I give diagrammatic illustrations of the gear, copied from machines with rolls of 10 ft. and 7 ft. in length respectively.

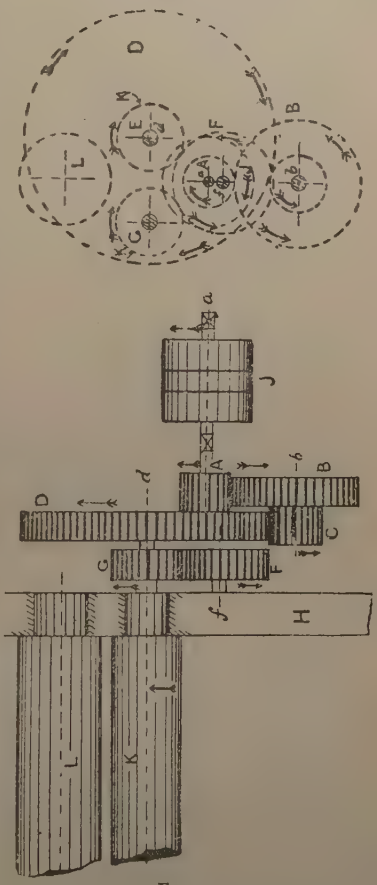


Fig. 111.

In Fig. 111, taken from 10 ft. rolls, A is the first-motion pinion on the shaft *a*, operated by the double sets of fast and loose pulleys J, driven with open and crossed belts alternately for reversal of the direction of rolling. A drives wheel B on shaft *b*, with increase of power and diminution of speed. Pinion C is cast with wheel B, or keyed on its shaft *b*, and drives wheel D on shaft *d*, again increasing power and diminishing speed, so that the gain in power between A and D is $= \frac{B \times D}{A \times C}$. Then there is a further gain between D and the pinions E and G, keyed upon the ends of the rolls K. Pinion E is keyed with the wheel D on shaft *d*. To make the pinion G on the other roll run in the same direction as E, it is driven through the pinion F, on a short independent shaft *f*, secured

to the housing H of the machine. The directions of rotation of these wheels and pinions are clearly indicated by the arrows. The total gain in power between the belt-pulleys and the pinions E and G $= \frac{J \times B \times D}{A \times C \times E \text{ or } G}$. The wheel F is an idle wheel, and does not affect the ratio. K K indicate the positions of the bottom rolls, L indicates that of the top one. In this machine the whole of the gearing is at the belt end, nothing but the bearings of the rolls being at the end opposite.

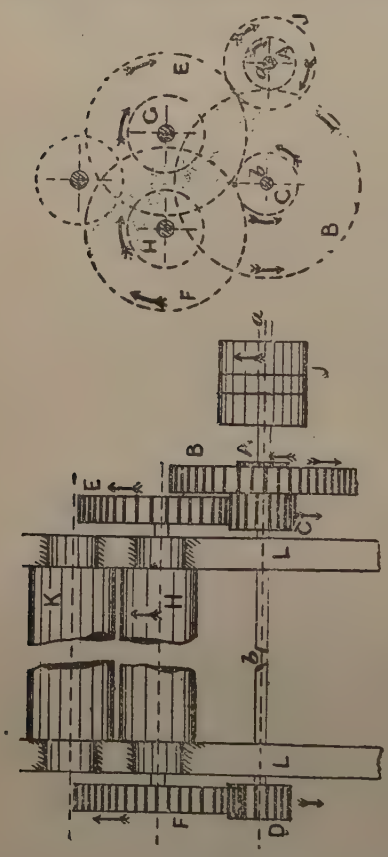


FIG. 112.

Fig. 112 shows another type of gear, distributed at each end, taken from a lighter machine with rolls 7 ft. long. Here A is the first-motion pinion, driven from the shaft *a*, by the pulleys J, with open and crossed belts. A drives wheel B on shaft *b* with gain of power. The shaft *b* extends right along underneath the framing of the rolls, and carries two equal pinions, C, D, keyed upon it. These pinions drive equal wheels, E and F; E being keyed on one roll, G, and F on the other roll, H. There is thus a double gain of power also, only the arrangement of gear is different. Since the wheels E and F would, by reason of their size, run foul of each other if placed at one end of the machine, they are placed at opposite ends of it, and that is the reason why the shaft *b* is carried right along underneath the machine, with the pinions C D at opposite ends

respectively. The arrows indicete the directions of rotation of shafts, pinions, wheels, and rolls. J J are the driving pulleys, K the top roll, L L housings. The gain in power is $\frac{J \times B \times E \text{ or } F}{A \times C \text{ or } D}$.

Bending Rings.—Plates are bent to all curvatures in the rolls—from long flat sweeps to complete circles. Unless the curves are very flat, several passes should be made to bring a plate to the form required, the plate being stressed less thereby than when one or two passes only are made. Usually the rolls are reversed at each pass, and the plate is run to and fro, the top roll being set down slightly between each passage of the plate through the rolls. In this way very quick curves are imparted easily, and without unduly stressing the plate. As a rule, when practicable, the rolling should always be done lengthwise of the grain, not crosswise. Rolling too quick curves crossways is apt to crack plates of inferior quality, while, as we saw in Chapter IV. page 48, even plates of good quality will stand much less bending, and consequently much less rolling, crossways than lengthways of the grain. The tests given in that connection will also serve to indicate roughly how far it is practicable to bend plates of a given thickness cold, and when it becomes necessary or judicious to heat them first in the furnace preparatory to bending. The thicker the plate, the less cold bending will it stand, so that while for a given curvature a thick plate would have to be heated, a thin one could be bent cold. In all rolling there must be tension and compression of the fibres on the convex and concave sides of the neutral axis. The more gradually this tension and compression are effected the better. Hence the reason why a plate is rolled to a quick curvature in several passes, and why also it is necessary to heat a thick plate before bending it to a quick curvature. And as the stressing is greater when a plate is bent to the envelope of a sphere than when it is rolled to the envelope of a plain cylinder, all plates which are hammered or pressed to the envelopes of spheres are heated in the furnace before being bent.

Another point in connection with rolling is this: that while a plate of flat curvature is drawn out from the front or back of the rolls in the same way that it was put in, one bent to a complete circle can only be drawn out endwise. The plate in Fig. 113 shows the limit of curvature at which a plate can

be drawn out from the front or back of the rolls; that is when the distance A between the ends is not less than the diameter A of the top roll. When the plate is turned round, the opening, of width A, will just clear the roll. Any distance greater than A will also clear; but anything less will not; and, of course, a complete ring, Fig. 114, can only be drawn out endwise. To permit a ring to be drawn out thus, one of the housings or roll standards is in some machines divided across between the top and bottom rolls, so as to be removable, and then the ring is slid out over that end of the top roll. Perhaps the majority of machines are made like this. In some instances, where the housings are undivided at each end, the top roll is made to slide out endwise; but it seems to me that the former plan is simpler and more preferable. Some machines again are not divided. In plated and girder work there is seldom any necessity for rolling complete rings, and then it is as well to have rolls with undivided housings. Of course, some little time is occupied in unscrewing the bolts that secure the divided housings; but it is unavoidable in rolling small boiler shells, pipes, and other circular sections. In the machine from which the gear in Fig. 111 is taken, the housing farthest from the gear is made removable. In vertical rolls, one of the rolls is usually made to lift out vertically.

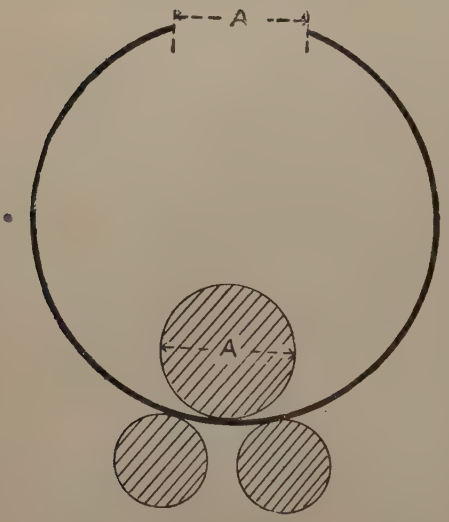


FIG. 113.

Bending Conical Forms.—Conical plates are rolled in detail or in sections. Thus Fig. 115, A represents a conical plate

divided out into convenient sections with chalked lines. The plate is not run through the rolls at a single pass, but each separate space included between the lines is rolled separately as a distinct radial segment of the plate, and the curves of the separate segments are also rolled and merged into one continuous sweep. This is done in order to produce a true cone. Without taking precautions of this kind the cone would not be regular, and the meeting edges would overlap in the manner shown at B instead of forming a perfect conic frustum like C.

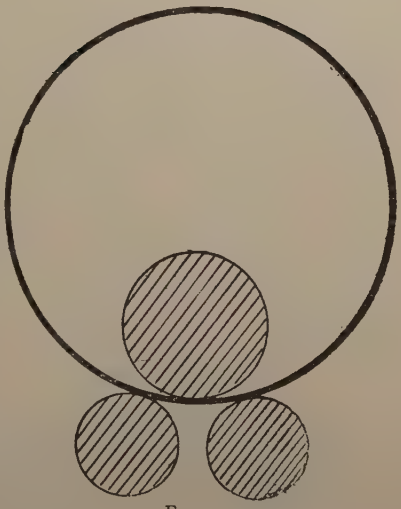


FIG 114.

Bending Sections of Plates.—Frequently one section only of a plate has to be bent, the other portions remaining straight, as in Fig. 116. Then the top roll is set down upon the plate gradually, bending it in that one section. If the plate is thin, this setting down of the roll will alone suffice to impart

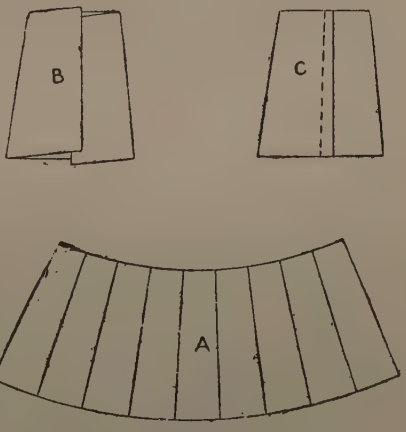


FIG. 115.

the short curvature. In the case of a stout plate a very slight rotatory movement back and forth is imparted to the rolls, just sufficient to impart the required curvature without affecting the straight portion of the plate.

Bending Envelopes of Spheres — The Use of Templets.—Plates whose curvatures are the envelopes of spherical surfaces cannot, of course, be bent with the rolls, but must be hammered to shape. In some cases, where it is desired to save the cost of an iron templet block, a recess is scooped in the dirt floor of the shop, rudely approximated in form to the desired shape of the plate, and the plate is hammered in this recess. Since the hole affords only a rude approximation to the double curvature of the plate, the skill of the workman is largely called in requisition in the work of hammering, and the curvatures of the plate at different sections are tested with iron templets, shaped like Fig. 117, the edge A being tried into the concavity of the plate B. The larger the number of templets made to different sections, the nearer will be the resulting approach to accuracy of the hammered plates.

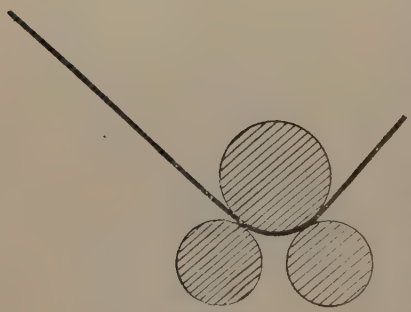


FIG. 116.

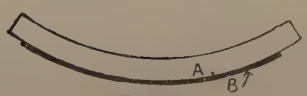


FIG. 117.

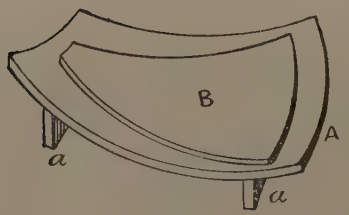


FIG. 118.

Such bending is not done cold, like that of most of the regular bending done in the rolls; but the plate, even though thin, is first heated to redness in the reverberatory furnace. Hammers are not used either, because they would bruise the surfaces of

the plate; but the wooden mallets illustrated in Fig. 35 on a previous page are employed.

It seems almost needless to say that this method of scooping out a hole in the ground, and hammering the plate into it, is not a method that is to be commended for anything except the most casual job. When two or three similar plates only have to be bent, then it will answer well enough; for any number over that quantity, a bending block of cast-iron should be made. Such a block is always made convex—not concave—because it is easier to hammer a plate into a concavity than round a convexity.

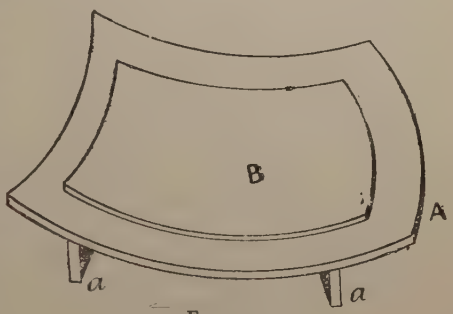


FIG. 119.

Bending Blocks—Various Types.—Figs. 118-120 illustrate typical bending blocks for hollowing plates into envelopes of spheres. The blocks A are of cast-iron, from $1\frac{1}{4}$ in. to 2 in. thick, dependent on area and on the thickness of the plates which have to be dealt with. They are usually made of larger size than the areas of the plates which have to be bent, as shown in Figs. 118-119, B. But in some cases they are cut to precisely the same outlines as the finished edges of the plates, and the edges of the plates are then marked from them, so that the blocks then fulfil the double function of bending blocks and of marking templets. The outer convex portions—the under sides of the blocks—are frequently laid in a concavity dug in the floor. A better way, because steadier, and because the blocks are strengthened thereby, is to cast stiff ribs upon the under faces, as shown at *a a* in the figures. When bending blocks are used, it is not so necessary to make use of templets, like that shown in Fig. 117, as it is when no block is used, the

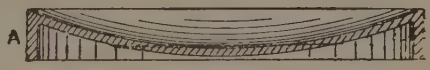


FIG. 120.

proper bedding of the plate in the block being a pretty good test of accuracy. But templets are frequently made use of as tests in good work for double security.

Fig. 120 illustrates a dished block, which is often used in jobbing shops for dishing the crowns of vertical boilers, and any similar dished plates. Sometimes the plate is dished between this hollowed block and a correspondingly convex top block.

When spherical work is done in large quantities, top and

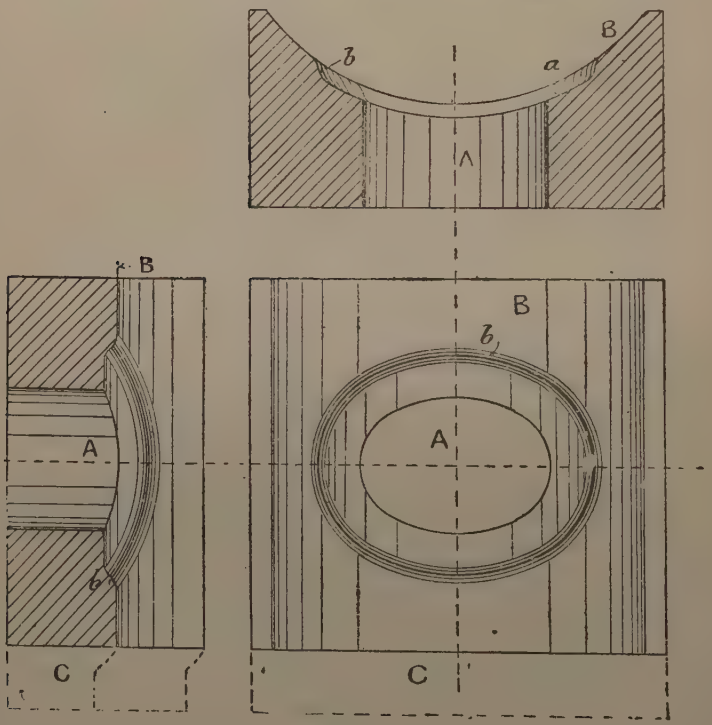


Fig. 121.

bottom dies actuated with a hydraudic press are employed. Since a good deal of flanging is done in this way, I will defer

remarks and illustrations thereon until a later stage, when I take up flanging (*see* pp. 200, 313).

Fig. 121 shows a block used for dishing-out that portion of the fire-box shell of a vertical boiler which receives the fire-hole ring. The size of the hole A cast in the block is of little importance, merely corresponding roughly with the size and shape of the fire-hole. The radius of the concave face B is the same as that of the fire-box shell, and the distance *a* equals the amount by which the shell is set outwards at the fire-hole ring; the edges *b* correspond with the radii of the plate where the setting-out is done. It is set with hammers while at a red heat.

Fig. 122.

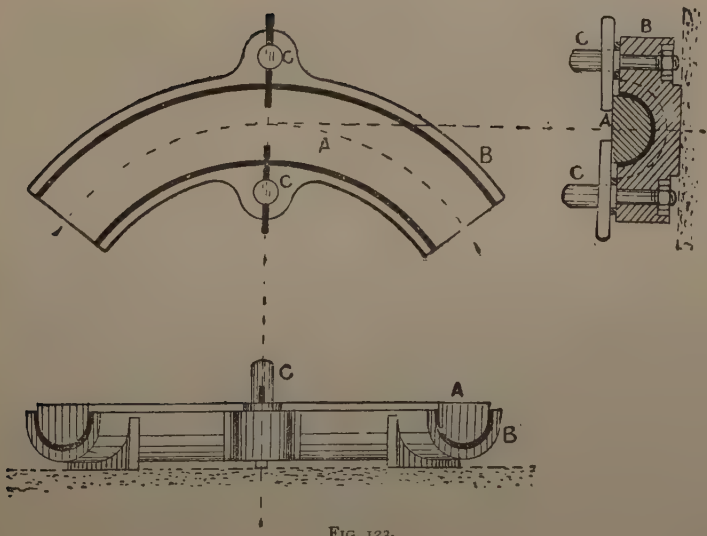


Fig. 123.

The dotted lines C in Fig. 121 show how such a block is modified for setting out the bottom edges of the fire-boxes of some classes of vertical boilers. These are set out thus to bring them into contact with their foundation rings through which they are riveted to the outer shell. The plates are hammered or dished out into the block after they have been rolled to the circular form in the bending rolls.

Fig. 122 shows a templet block used for bending a lot of steel bend-pipes. This is a troublesome job, and it would be almost impracticable to make them without a block of this type. The difficulty is with the double curvature. Properly, they should be finished between top and bottom dies, closed with strong pressure.

Fig. 123 illustrates a more complete method of bending the sheets for large wrought-iron and steel bend-pipes. Here top and bottom dies, A and B, of cast-iron, are made use of. After the sheet has been roughly hammered into outline in the bottom die B, it is reheated, and the top die A is pressed down upon it with the cottar-bolts C.

CHAPTER VIII.

BENDING ANGLES, &c.

Type of Forge used for Heating Work.—Anvil.—Block for Levelling and Bending.—Stand for Small Blocks.—Various Blocks.—Conical Stand.—Method of Bending Easy Curves.—Method of Bending Quick Curves.—Bending Internal Angles.—Bending External Angles.—Bending of Small Rings.—Limits to Curvature Imparted.—Rig-up of Small Blocks.—Bending Angular Forms.—Crinkling.—Notching for Welding Corners.—Bending of Tees.—Bending of Rails.—Bending of Foundation Ring.—Bending of Man-hole Ring.—Machine for Bending Angle-Irons.—Furnace for Heating Angles.

Type of Forge used for Heating Work.—Section irons are for the most part bent on blocks, and not often in special machines. The latter, however, are used when large quantities have to be bent to the same curves or angles; the former for the ordinary or average jobs of the shop. I shall describe both in considerable detail, since this class of work demands a fair amount of skill, and a good deal of judgment in the designing and rigging up of tackle. But first a few remarks should be devoted to some essential appliances necessary for the preliminary work of heating and bending; for since nearly all section irons are bent in short sections at a time, they are not so often heated in the reverberatory furnace as at the forge. It is chiefly for heats of considerable length or area that the furnace is used, and for plates more than for bars and sections, so that nearly all the work to be described in the pages immediately following is done at the forge, and is therefore the work of the angle-iron smith rather than of the plater. Many of the common forge tools used were shown in Chapter II. It only remains now to illustrate the type of forge used by angle-iron smiths, the foundations upon which the bending blocks are laid, and a few typical bending blocks selected from a large number.

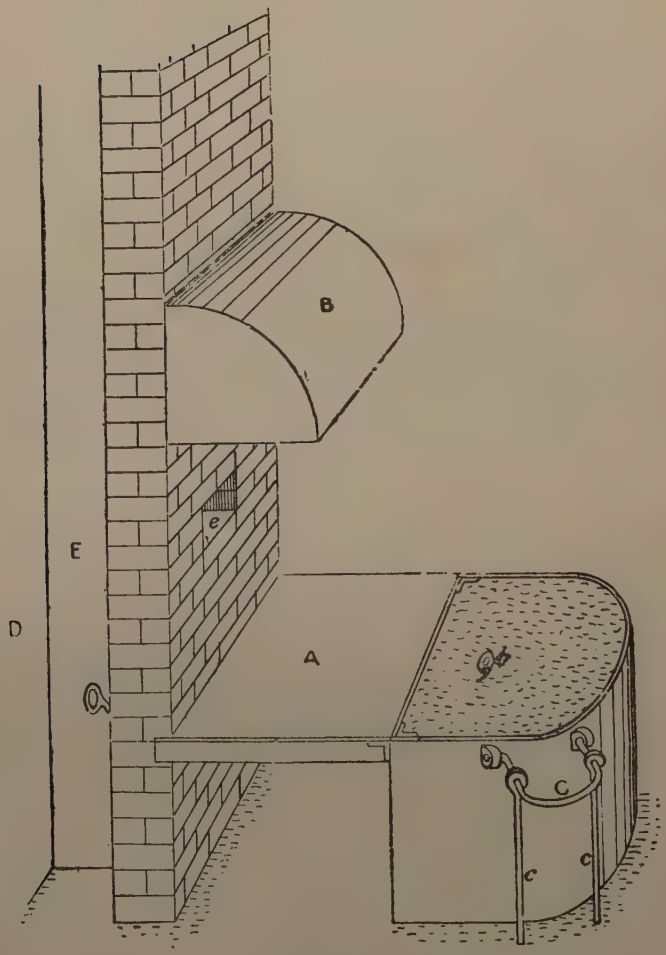


FIG. 124.

Fig. 124 illustrates in perspective the ordinary type of forge. It is built of angle-iron, sheet-iron, and bricks. Roughly, the bed of the forge may measure 6 ft. out from the wall by 4 ft. in width; or 5 ft. by 4 ft. and about 2 ft. in height. Its area will depend on the class of work done in the shop. The forges in a shop are not all of the same size. Frequently two forges are used by one man at once, as in welding, where the main work is being heated at a large forge, while a welding-strip or "glut" is being heated simultaneously at a smaller forge adjoining. It will be noted that the bed of the forge is brought out farther from the brickwork than an ordinary smith's forge is, leaving an area, A, of sheet-iron unoccupied with the fire. This is done because of the necessity for handling long

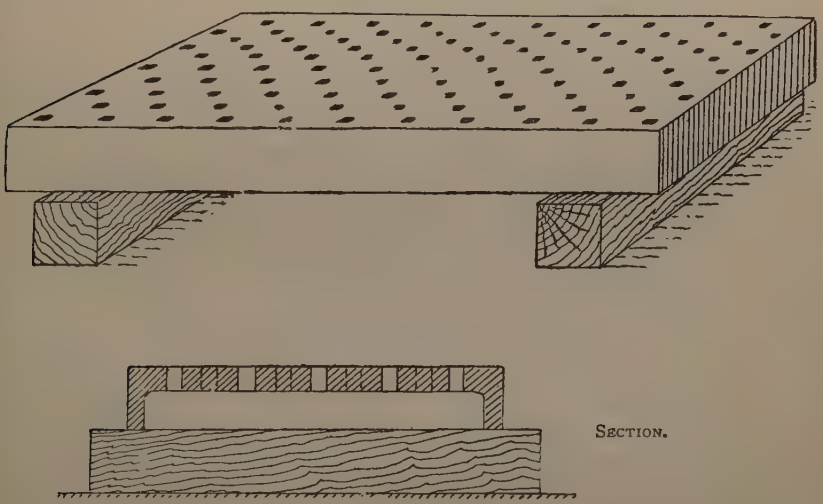


Fig. 125.

bars of section iron in the course of formation to large circles or curves, the greater portions of which have to lie outside the fire on the hearth, and for which there is room on the area A. Sometimes, also, the hood B is removed altogether, to allow of the better manipulation of curved and angular work standing up from the fire. There is a special appliance also, shown at C. It is an adjustable stand for supporting the overhanging

ends of work of considerable length which is being heated in the fire. The stand can be raised or lowered in a moment by means of the legs *c c*.

The general construction of such a forge is apparent from a glance at the figure. It is made of angle and sheet iron, built into the brick backing. The tue iron passes underneath the sheet A, its nozzle being seen at *b*. These forges are always supplied with blast from a fan, or a pressure blower, and the handle by which the throttle valve is adjusted for the regulation of the blast is situated at the left hand of the brickwork, shown in the figure. The relation of the forge to the wall of the shop is indicated at D, which represents the wall, E being the chimney into which the smoke discharges through the opening *e*.

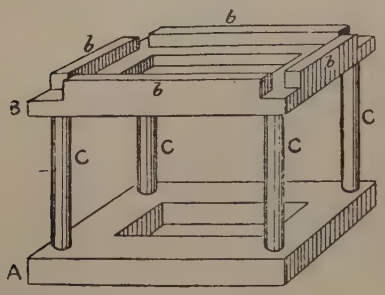


FIG. 126.

Anvil.—An ordinary smith's anvil, rather massive, weighing, say, 4 to 5 cwt., is used by angle-iron smiths. I need not illustrate this. It is carried in an iron stand of the usual type employed by engine smiths.

Block for Levelling and Bending, and Stand.—There are two appliances which serve as the foundations for nearly all bending operations—the massive block (Fig. 125) with holes, and the stand, Fig. 126.

The first (Fig. 125) is made of any size convenient for the requirements of the shop. It is similar to a levelling block, only that, being used for bending, it is pierced with a large number of holes for bolts, pins, and holdfasts. These holes may be either round or square. The second (Fig. 126) consists of a bottom A, and top B, each of cast-iron, united with four wrought-iron legs C, firmly riveted between them. Ribs *b* are cast around B to confine the bending blocks, which are made to fit within them. Such a stand may average about 18 in. or 20 in. square.

Various Blocks.—There are many special blocks which will appear in the course of future illustrations, so that I will

only indicate here briefly some general and typical outlines of the blocks employed for bending section irons.

Fig. 127 is a type of a curved block used for bending angles to long sweeps. It is held down on the plate in Fig. 125 by means of pins, or bolts passing through its holes to the holes cast in the plate. The inside of the angle-iron lays around the

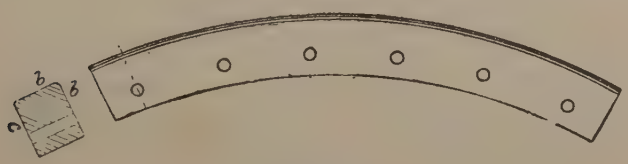


Fig. 127.

faces *b b*, the face *c* resting upon the plate. Fig. 128 is a block used upon the plate, or else upon the stand (Fig. 126) for bending angles to various angles and curvatures, corresponding with those to be given to the work. It is a kind of stock block, of which several may be kept, giving right angles *a*, two acute

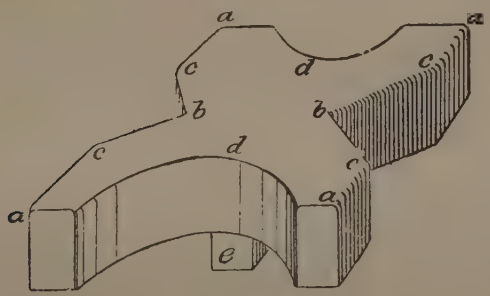


Fig. 128.

angles *b*, two right and left handed obtuse angles *c*, and two curves *d*. The pin *e*, of wrought-iron, cast into the block, fits one of the holes in the plate (Fig 125). Fig. 129 is a block for use on the plate or in the stand. It gives four separate angles *a*, for bending angle-irons around. This also is a standard block kept in various sizes and angles for general work.

Fig. 130 is a block for bending tee-irons upon. It is bolted to the plate through holes cast in the flanges A, or is sometimes clamped upon the stand (Fig. 126). The tee-iron is bent around the face B, the vertical web dropping into the recess *b*. These blocks are made of various angles. The one shown in the figure is made for different angles at each end. The slot hole C is for the insertion of a cottar to hold the flat web of the tee, which lies upon the top of the block during the bending of the ends of the iron over the angles. The various methods of clamping angles and tees will be illustrated, together with the details of methods of heating and bending. Angle-irons, as well as tees, can be bent upon this block. Fig. 131 shows a block used like the last, for bending tee-irons, and also angle-irons upon, if need be. But this is

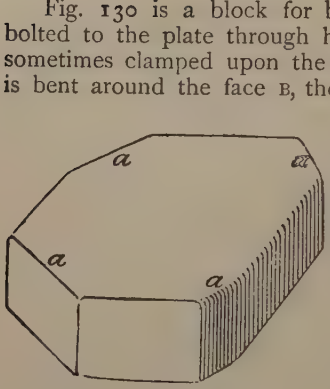


Fig. 129.

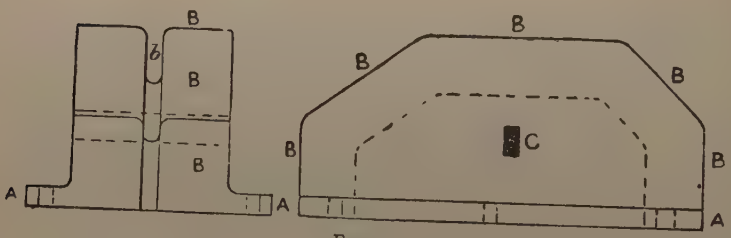


Fig 130.

specially made for acute and obtuse tees and angles. Also, when occasional small quantities of angle and tee are wanted of acute type, they are so bent from common square angles and tees, upon this block, instead of ordering them of acute form from the mills. The flat faces of the irons are bent against the faces A, and the vertical webs drop into the recesses *a*. B is a pin for use on the plate, being an alternative method to the flanges A in the previous figure.

Conical Stand.—Fig. 132 is a conical stand of cast-iron, largely used, not much for bending, but for imparting a neat and finished circular form to rings of various kinds that have been bent and welded on other blocks. Such stands are made from about 2 ft. to 5 ft. in height, and other dimensions proportional. The thickness of metal will range from 1 in. to

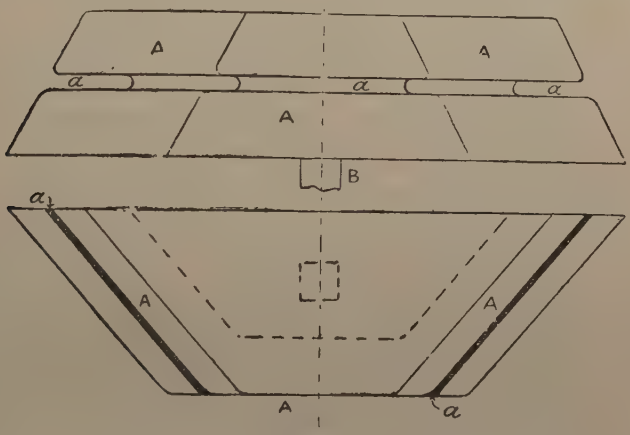


FIG. 131.

1 ½ in., depending on size. The bottom flange A is simply for the purpose of affording a steady base to the stand.

Method of Bending Easy Curves.—There are two general methods of bending section irons: one over blocks of the type shown in Fig. 130, the bending taking place in a vertical plane; the other round blocks of the general type shown in Figs. 127–129, the bending there being done in a horizontal plane. In the first case cottars and straps are commonly used to confine the section irons around the block; in the second, pins and wedges, or straps, or clamps, are used for the same purpose. Speaking generally, but not by any means absolutely, the first method is suited to irons of no great length, the second to those extending to lengths of several feet. It is more convenient to bend long strips in the horizontal than in the vertical plane. If bent in the vertical plane the lower ends would often be prevented from freedom of movement by

coming in contact with the ground, while, if bent in the horizontal direction, there is ample room for their movement.

If an angle has to be bent to a long easy curve, it can be done to a templet without the aid of any special bending block, as in Fig. 133. In this case that portion of the angle which has to be bent is heated either in the reverberatory furnace, or in the forge fire, as happens to be most convenient. It may be done in one heat, or in two—a heat for each curve; also depending on the size of section and on the length of the part which has to be curved. Pins are put into holes which happen to be suitably situated in the bending block, and the angle-iron is pulled round at one end by hand against the pins, as fulcra, into curves rudely approximating to those required. Thus in the figure, pins would be inserted at A A, B B, C C′, and the end D of the angle would be pulled round to form the curved portion *a*. Then pins would be inserted at E, F F, and the end D pulled in the opposite direction to form the curve *b*. The holes in bending blocks are cast so numerous that there is seldom any difficulty experienced in finding holes for any required function. As in the case of C′ if the nearest hole available does not come quite right for the curvature wanted, a bit of iron or a wedge is inserted to fill up the space between the pin and the work.

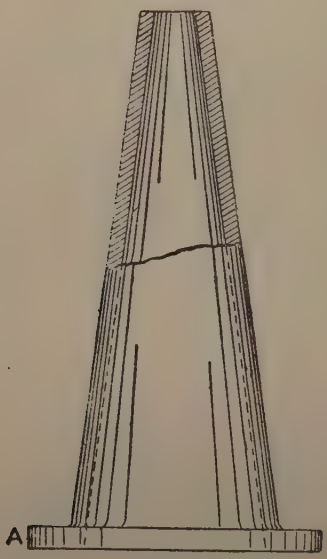


FIG. 132.

The rest is a matter of adjustment. The regularity of the curves is checked by means of templets. The horizontal web becomes puckered by the bending, and the vertical web will not stand square. The flatter is used to remove the puckering from the horizontal web until it lies flat upon the block, and the vertical web is set as required with the sledge. When

blows are dealt with the sledge in this way, the striker holds another on the opposite side, not quite opposite, but adjacent thereto, to supply the necessary support and leverage against the action of the blow. This was noted in Chap. VI., p. 87, in connection with Fig. 94.

Method of Bending Quick Curves.—Fig. 134 shows the general method adopted for bending quick curves. This example differs from the last in the greater quickness of the curved portions, which necessitates the use of a special block, A. This block is cottared down upon the bending block B, and affords a rigid templet and guide for bending the angle-iron C around. It is held down with the cottar D, taking its bearings on the block A in the bolt E. The angle is pulled round this block by the free end D to the curve *a*, the necessary resistance being afforded to the straight portions by the pins F inserted in the bottom block.

The second curve is a repetition of the first, the block being shifted, or a second block G being cottared down where holes are conveniently situated, and the iron bent round to the dotted outline *b*.

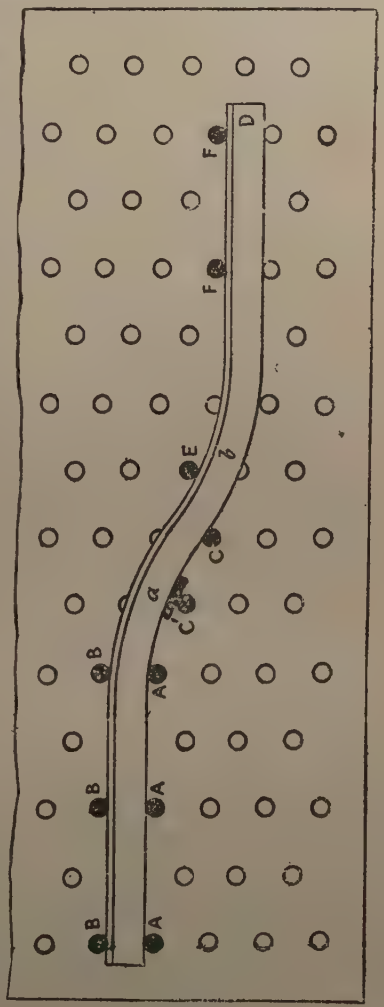


FIG. 133.

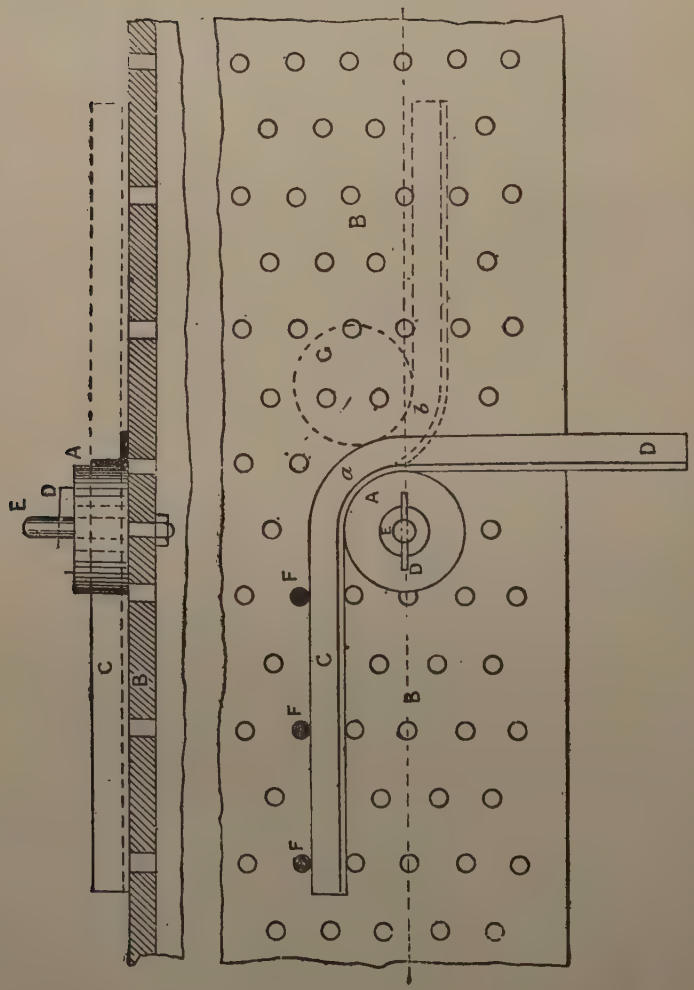
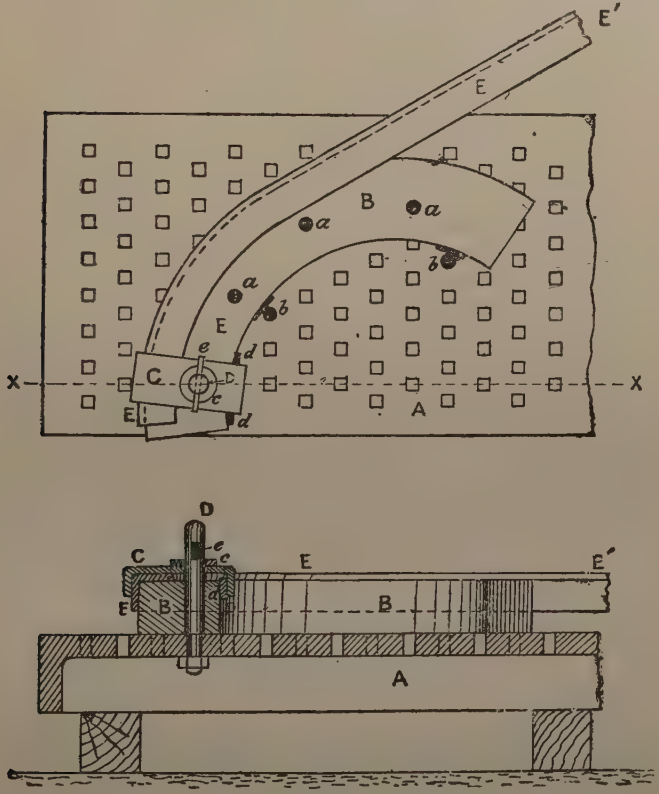


FIG. 134

Bending Internal Angles.—Fig. 135 illustrates the method by which internal angles are bent to long, regular curves with the aid of a block. A is the bottom or levelling block, and B the bending block, having its outer edge made to



SECTION X—X.

FIG. 135.

the curve to which the angle E has to be bent. It is held down on A by any convenient method, as by pins passing through holes *a* cast in it, or through lugs cast on its concave face, or it is simply thrust against pins *b* put into holes conveniently

situated in A. These are matters of choice. One end of the angle, heated to any convenient length—in the reverberatory furnace if long, in the forge fire if short—is then rapidly cottared down upon one end of the block. The fastening C shown, consists of a strap which embraces and clips the outside of the vertical web of the angle E, and the inner vertical face of the block. A hole is pierced through the strap to permit the cottar bolt D to pass through, and the driving in of the cottar *e* binds the clip down upon the angle block. *c* is a washer. A wedge may be inserted at *d* if necessary to pull the strap up tightly against the face of the angle-iron web. When secured thus, the free end E′ of the angle-iron E is pulled round against the block. The figure represents this early stage of the operation. The bending is assisted by the use of the sledge, which reduces the puckering inevitable in all bending operations of this character, and causes the angle to bed upon and around the block more closely than it would otherwise do. If the length of angle to be bent is considerable, and of regular curvature, it is not necessary to make the bending block B of the same length. If, say, the angle were 10 ft. or 12 ft. in length, the block might be 2 ft. or 3 ft. only, and then the angle would have to be unclamped and heated and bent in sections of 2 ft. or 3 ft. in length.

FIG. 136.

When long pieces of angle are being bent round blocks, the leverage due to their length is sufficient to enable the striker to pull them round by, assisted by leverage obtained with a bar thrust into holes adjacent and pressed against the angle. But in short lengths the leverage is correspondingly less, and then an appliance like Fig. 136 is sometimes used, being slipped over the free end of the angle, and the pull being made at the end A. The backs of the webs lie against the faces B B, and the tapered prong C fits into the interior of the angle. Being tapered, it will fit angles of two or three different sizes. The same appliance is used for other operations in connection with angle-iron, such as turning it about during cutting off and

welding. The hole in the boss D is for the insertion of a lever for turning heavy angles round about during such operations.

During the bending of any angle-irons a considerable amount of puckering up or crinkling of the webs occurs, and this has to be corrected simultaneously with the work of bending, and mostly while the iron is at a red heat, though slight and final corrections can be made after the irons have become cold. This is done partly with the hammer or sledge, partly with the flatter, the employment of either depending on the amount of puckering present. As far as practicable this is done against the bending block; but the finishing corrections have often to be done away from it, upon the levelling block, the latter affording a perfect test for the truth of the horizontal web, and a set-square being used to test the vertical web. In these corrections the value of the levelling and bending blocks is evident, the former for correcting the puckering of the horizontal web, the latter for that of the vertical webs. Having such blocks, the straight-edge and square are of relatively little service, the level block or the vertical faces of a bending block giving broad areas of contact not possessed by the straight-edge and square.

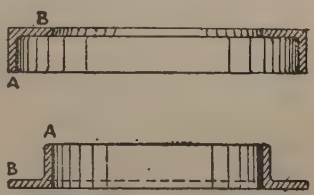
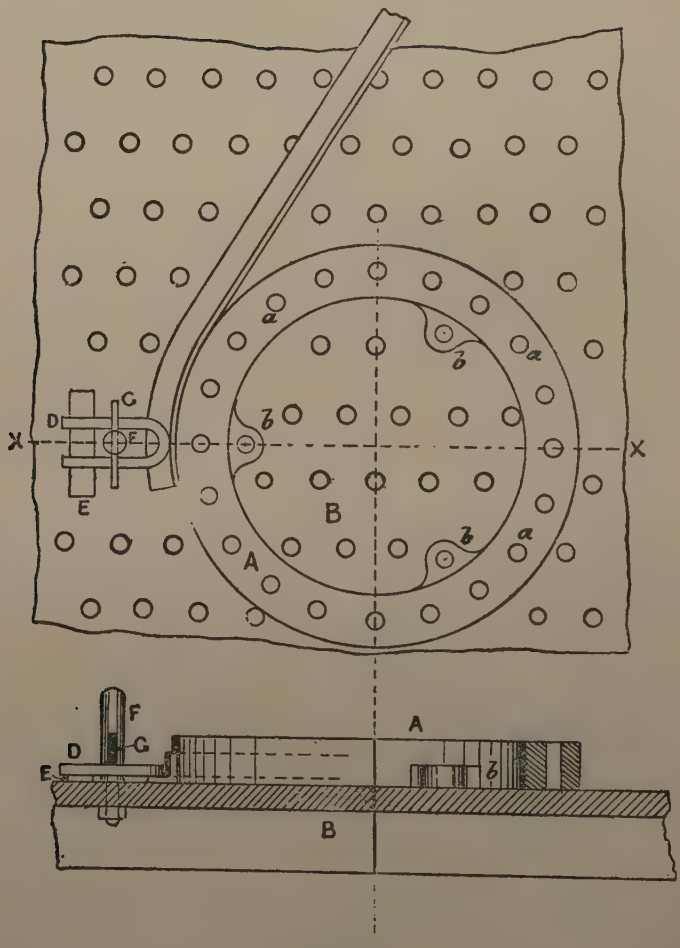


FIG. 137.

The quicker the curvature imparted to an angle, the greater the amount of crinkling which will result. It is, of course, greatest in the web parallel with the plane of bending—the horizontal flanges in Fig. 137. The reason is obvious. The length of a straight piece of angle-iron for a given circumference being measured on the vertical webs A A, Fig. 137, then in the internal ring shown in the top figure, the web B will be in great compression, being squeezed into a smaller space, with the result that it will spring upward and downward under the forces of compression. In the external ring, shown in the lower figure, the web B will be in great tension, and the tendency will be to fracture in one or more spots, and if it does not fracture it will tend to coerce and pucker the vertical rib A. What is seen so obviously in such extreme cases takes place in a lesser degree in all curves: the flatter the curve, the less in amount is the puckering. We shall meet with other illustrations as we go along.



SECTION X—X.

FIG. 138.

Steel being more ductile than ordinary iron, is better adapted for the bending of very quick curves than such iron. Hence quick curvatures which could not be bent in iron can be done in steel without risk of cracking. Also the absence of the lamination in steel, which is so common in iron, makes sounder work possible when quick curves are concerned. Most flanged work, too, has to be riveted, and a good mild steel will suffer less by loss of strength due to rivet holes than iron, because of the greater stress and tension set up in the latter by the operation of bending. For this reason also steel is better for bending than iron.

Work which is bent, moreover, suffers frequently from the same evil to which much hand-flanged work is subjected, namely, the loss of strength due to hammering, &c., done while at a blue heat. The later stages of bending and setting are often performed when the red heat has given place to black, and this is a most dangerous temperature to work at, producing brittleness and loss of strength. Such setting and finishing with hammer and flatter should therefore either be done when the metal is red hot or when it is quite cold, otherwise incipient cracks are likely to be started in the edges of the work.

The foregoing remarks and those to follow apply in the main to other sections than angles and tees. There are few of the sections in the group, Fig. 79, p. 65, which have not sometimes to undergo the processes of bending to a greater or less extent, and in many cases, of welding also. And bending may have to be done in either plane—that is in the plane of the narrower or of the wider section — some tasks being relatively easy, others troublesome, involving notching and welding. But since every separate job involves different conditions, the judgment of the workman alone can guide him, and from past experience he will infer whether a given job is practicable or whether it is not.

If, therefore, I treat at length of the bending and welding of angles, which are the sections that most commonly occur, the principles thus laid down will suffice for general guidance in the bending of all other sections, as tees, channels, &c.

In all or almost all cases blocks of suitable type, having sections adapted to the sectional forms of the work which has to be bent, will have to be devised and rigged up. How these should be made will be evident from a study of the similar forms which I shall now illustrate.

Bending External Angles.—Fig. 138 illustrates the bending of a large complete ring with the flat web of the angle situated externally. When bending complete rings, it is always better to make a complete templet bending ring for the purpose, rather than a short length only, as in Fig. 135. It is then easier to bend the ring truly, because the block becomes the gauge by which the circle is tested, and likewise the vertical accuracy of the vertical web. The bending block A is held

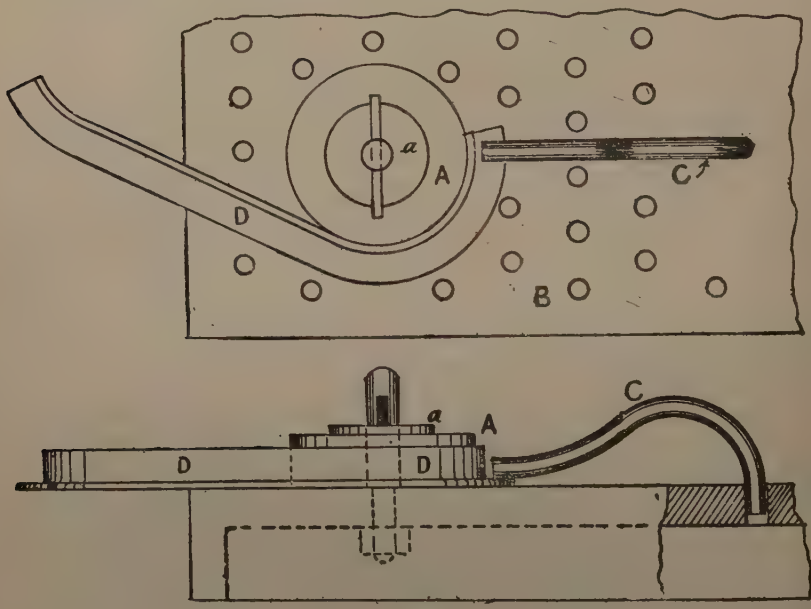


FIG. 139.

down upon the levelling block B, either with cottars or pins passing through holes *a*, conveniently situated, or through internal lugs *b*. Plenty of holes *a* are generally cast in as shown, so that some are sure to be available for use, though all are not wanted at one time. One end of the angle, for a length of, say, from 16 in. to 20 in., is heated and clamped down upon the levelling block by any convenient method, that shown in the figure being as common as any; D is simply a bit

of square bar bent rudely into a horseshoe form. The bent portion is laid upon the horizontal web of the angle, the opposite ends resting on a bit of square bar E, of about the same thickness as the web of the angle. A cottar bolt F is passed through into one of the holes in the levelling block, and the whole made fast with the cottar G. The angle is thus pinched down so that it cannot move, while the free end is pulled round against the block A. The advantage of the method of clamping shown is that the fastening can be made and unmade in an instant—a point of prime importance in working heats. Screw fastenings would be altogether too slow, the work losing much of its heat while the fastening was being secured.

When the iron has been bent as far as the heat will permit of, the fastening is knocked off, and the succeeding section of the iron is heated and bent in precisely similar fashion to the first. As the work proceeds, pins may be put into the levelling block, and wedges driven between them and the edges of the iron already bent, to keep it close up against the block. Or,

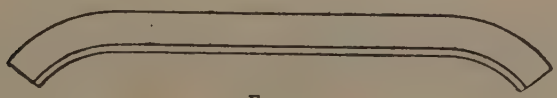


FIG. 140.

alternatively, two or three more fastenings like that shown may be used for the same purpose. Fig. 139 illustrates the bending of a complete ring of small diameter. It is one for the uptake or chimney of a vertical boiler. Such a ring as this affords an example of the limit at which it is practicable to bend angles; such small rings sometimes cracking in the process around the external portion of the horizontal web. A is a block cottared down upon the plate B, *a* being a washer only, and the diameter of the block is the same as that of the interior of the ring. Before bending the ring it is necessary to first bend both ends to the correct curvature with the sledge, Fig. 140. If this precaution is not taken, it is very difficult to complete a perfect circle at the ends afterwards. The ring is next heated, one end clamped down to the plate, and against the block by means of the holdfast C. Then the angle D is pulled round the block with the tongs to form the ring at one heat.

Bending of Small Rings—Limits to Curvature Imparted.—There is a limit to the curvature to which angles can be readily bent. The small rings, Figs. 137 and 139, proportionately drawn in respect of diameter and section, can be done pretty easily, but rings a little smaller approach that limit. It is, of course, a question of proportion, a light angle being capable of bending to a smaller curvature than a heavy angle. Thus the proportions of the figures will correspond with rings of about 12 in. diameter, with an angle section of 3 in. by 3 in. It would be exceedingly difficult to make rings 3 in. or 4 in. smaller, of ordinary iron, by bending simply. With Yorkshire iron, of course, one can do almost anything. Good steel also will stand more bending than ordinary iron; but the latter will almost certainly crack around the edges B, Fig. 137, owing to the great tension set up there during the bending operation. I shall show directly what devices are resorted to in cases where it is impossible to bend angle-irons without fracture, as where they are bent to right angles.

If an angle-iron ring has to be bent, and the section of the angle is other than 90°, being either acute or obtuse, "close," or "open," then it does not pay unless a large number of rings are wanted to order the angle of the section required. It is usual in such cases to take an ordinary angle of 90°, and close or open it as required. This can be done either between vee blocks under the hammer, or against the edge of a block suitably bevelled, and bolted down upon the shop bending block.

There is an alternative way of making small rings of angle section suitable for uptakes, without bending and welding. It is to stamp them in a die block with a conical punch out of annular pieces of plate. The diameter of the hole in the die block is the same as the outside diameter of the vertical flange of the angle ring, and the diameter of the largest portion of the punch is equal to that of the inside of the vertical flange through which the uptake passes. A good radius must be formed around the edge of the die, forming what is the throat in an ordinary angle. Steel plate must be used, as ordinary iron will not stand the work. One heat is sufficient to form a ring, the punching being done under the steam hammer.

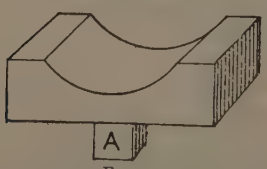


FIG. 141.

As I am not now writing of welding, I shall say nothing about the welding-up of a ring like Figs. 138 and 139, but leave that subject until I treat of it specially, after I have done with bending (*see* p. 152). The problem of the estimation of the correct lengths required to form rings and frames of given dimensions is also outside the present connection. Consideration is given to that on p. 258.

Rig-up of Small Blocks.—For much odd work no special blocks are made; but stock blocks, which are kept in large quantities in most shops, are utilised, the nearest available for a given purpose being selected. Typical blocks were shown in Figs. 128 and 129, pp. 119, 120. Two others are shown in Figs. 141 and 142.

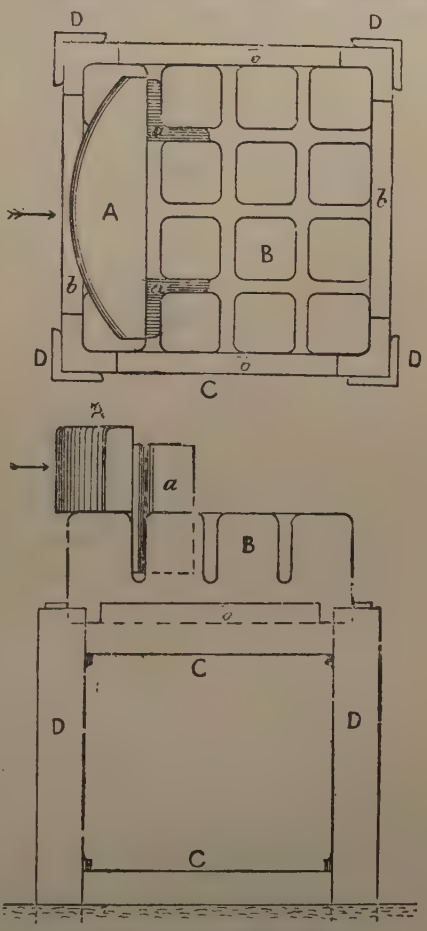


FIG. 142.—PLAN AND ELEVATION.

Fig. 141 is a concave block used upon the anvil or on the levelling block, the pin A, of wrought-iron bar, cast into it, fitting into the hole in the anvil or into one of the holes in the levelling block. Such concave blocks are kept in various curvatures, and are used for bending short concave sweeps in any jobbing work.

In Fig. 142, A is a convex block, of which there are also many such kept in stock. This is shown rigged up on the block B, which was illustrated in Fig. 84, p. 76; and this, again, is set upon the stand C, which was shown in Fig. 126, p. 118. Of course, there are many ways improvised for rigging up the various bending blocks, so that those which I illustrate are a few only out of many. In the figure the block B is laid upon the stand, and is confined by the strips *b* cast upon the stand. The bending block is laid upon this, and is prevented from movement under the force of the hammer-blows by two strips of angle iron, *a*, set vertically in slots conveniently situated in the block. The stand is sometimes confined also by means of angle-irons, D, driven into the ground at the four corners. This is only necessary when heavy side blows are being given, as there would be in this case, the blows coming mostly in the direction of the arrow, and not for vertical blows. When small blocks like those in Figs. 141, 142, are employed for temporary bendings, there is no clamping done as a rule. The work is bent with the sledge, the length of the curvature being inconsiderable, and not worth while rigging up the tackle for, shown in Figs. 138, 139.

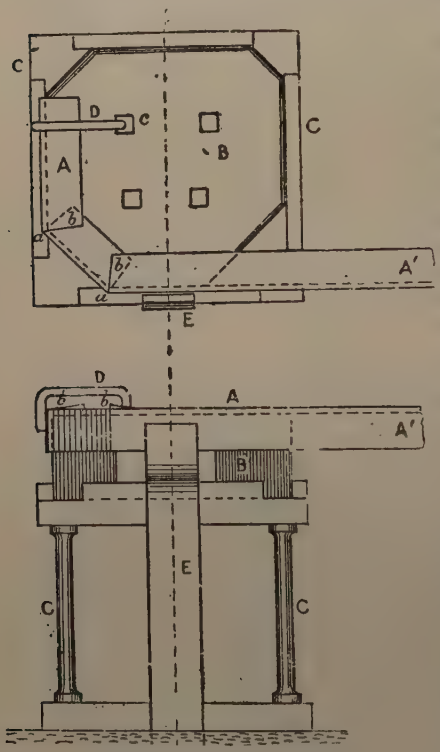


FIG. 143.—PLAN AND ELEVATION.

Bending Angular Forms—Crinkling—Notching for Welding Corners.—Fig. 143 illustrates the bending of an angle-iron stiffener A, on a cast-iron block B, laid within the same iron stand C as that shown in the previous figure.

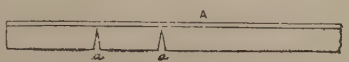


FIG. 144.

Now though, as we have seen in a previous page, 132, an angle can be bent to a regular curve of long or of even moderate radius without fracture or crinkling, it is not practicable to bend angle-iron and steel into any very obtuse angles without their becoming unduly crinkled up. Hence, in such bending of angles, welding and bending have to be combined in order to prevent the crinkling up of the horizontal web, as follows:—

Let A, Fig. 144, represent the piece of angle-iron before bending. Two chalk-marks are made upon it at the positions *a a* corresponding with the corners *a a* shown in the angle when bent upon the block, in the previous figure. The angle is heated in the forge fire at those localities, and the horizontal web is divided as shown at *a a* with the hot-set, the edges of the cut being of necessity bevelled, and a narrow vee-shaped portion removed, just as shown. The angle is then put back into the fire and re-heated, after which it is taken out and one end clamped upon the block B, Fig. 143, by any convenient means—in this case with a wrought-iron clamp D, clipping the angle upon the outside and against the opposed face of the square hole *c*, of which four are cast in the block. While clamped thus, the free end A′ of the angle is pulled round by hand until it very rudely lays round the angle of the block B, as seen in plan. During this pulling round, both vertical and horizontal webs become crinkled or corrugated, standing out-and-in, almost anyhow; and the angle-iron smith has now to correct these irregularities with hammer and with flatter. Further, there is the weld to be borne in mind. This is a lap-weld, and the preparation for it consists in bringing the overlap of the cut portions *a a*, Fig. 144, above and below one another, as seen at *b b* in both Figs. 143 and 144. This overlap takes place of necessity, as the angle-iron is pulled round the block B, and what the smith has to do is to make it neatly, one cut end below, the other above, as shown at *b b*.

At the same time the horizontal and vertical webs of the angle are made to lay close against the block B; first the sledge, and then the flatter, being used to effect this. And as the free end A′ of the angle is very liable to start away from the block, especially when it is of considerable length, it is confined either with another clamp like D, which, however, has the disadvantage of preventing end-long movement of the angle, which may need to take place, due to the closer setting round of the portion that goes round the angle of the block B, or with a device shown at E. This is simply a flat piece of iron bolted to the side of the stand C, or else driven into the ground and brought close to the vertical web of the angle-iron. This permits the angle to move along endwise, while it prevents it from buckling outwards away from the block B.

I do not propose to enter into the subject of welding in this connection, but have treated that in a special chapter (IX.) So having bent the angle in readiness for welding, we leave it for the present. And this accords with the usual practice of the shops. For if any number of similar angles or rings were wanted, they would all be bent and set aside to be welded subsequently. Diverse operations are not mixed up indiscriminately, for that always means loss of time and sacrifice of aptitude.

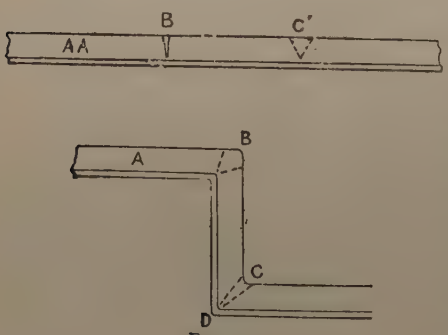


FIG. 145.

Square and oblong frames and stiffeners often have to be made for the internal portions of box girders. Then the frames have internal webs. Often, too, angle-irons have to be bent to form external frames for structural plated work. If we take one corner only of each type of frame that will suffice. Fig. 145 shows an angle A, bent at the external corner B, and at the internal one C. It is obvious that such corners cannot be bent like long curves by a mere stretching of the metal at B, or

compression of the metal at C. Both corners must be cut, and when cut there will be a *gap* at B, shown by the dotted lines, and an *overlap* at C, also shown by dotted lines, and in each case there must, of course, be welding up also. The upper part of the figure, AA, shows the piece of angle previous to bending, and also the manner in which it is cut; at B′, corresponding with the corner B in the lower figure, there is just a little nicked out with the hot-set, as in Fig. 144 *a a*. This permits of the bending round of the angle, the nicked space opening out as seen dotted at B below. At C′, corresponding with C in the lower figure, a wide nick is cut, which on the bending of the angle not only closes, but overlaps in the same manner as the overlap occurs in Figs. 143, 144, *b*, *b*. Afterwards the overlap at C is welded, and the opening at B is welded with a "glut" or "filling-in" piece. But something more than this is necessary in the formation of a keen angle like that at D. It is necessary to set the angle out at that part before bending, otherwise the corner D could not be bent quite square, but would be more or less rounding. Hence the practice is to set out the web of the angle-iron at that section with a fullering tool, B, as shown in Fig. 146, D in that figure corresponding with the corner D in the previous figure. A is the angle being bent, and C C are simply two round rods of iron placed beneath the angle to offer contiguous points of resistance to the action of the fullering tool, the blows upon which are delivered by a striker.

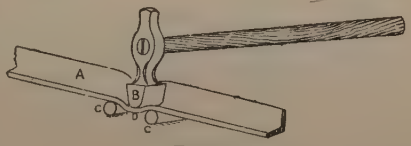


FIG. 146.

Figs. 147, 148 illustrate the bending of the exterior angles around their respective blocks. In Fig. 147, A is the angle bent round, with the gap B open, previously shown dotted at B in Fig. 145. C is any rectangular block secured to the levelling block, or upon an intermediate block upon the stand already illustrated in Figs. 142, 143. D D are pins, and E E wedges by means of which one side of the angle is held firmly against the block C, while the free end A′ is pulled and set round. Then the angle is removed ready for welding.

Fig. 148 illustrates the bending of an angle, A, to the interior angle C. The side A is held fast with a clamp, B, to

the bending block E, one end of the clamp gripping in the hole *a*, as in the similar case illustrated in Fig. 143. The free end A of the angle is pulled round, producing the overlapping of the web at C required for welding. The fullering out of the vertical web shown in Fig. 146 has the appearance seen at D, a slight protuberance, which, being set-in with the flatter, makes a neat corner quite square, and without any thinning down of the metal there. Then the corner is ready for welding. Sometimes an internal angle like C is not overlapped, but the joint is left slightly open, and the weld is made with a narrow glut-piece, like that used at B in Fig. 147, but narrower.

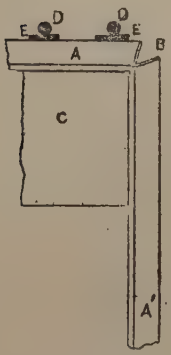


Fig. 147.

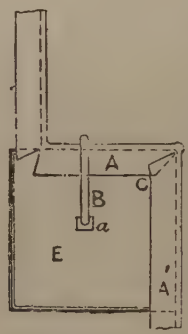


Fig. 148.

Bending of Tees.—Tee-irons are conveniently bent to curvatures over blocks of various kinds. The blocks are so made and fixed that the bending of the irons is done either in a horizontal or in a vertical plane. In the first case the block is laid upon and bolted down to the large levelling or bending block with the grooves for the web of the tee at the side. In the second case it is laid upon the levelling block, or upon the stand shown in Fig. 126 with the groove for the web uppermost. In some cases it is segmental only, in others it is convenient to make it a complete block, circular or otherwise, depending on the nature of the work which has to be done. Such blocks are almost invariably of cast-iron.

Fig. 149 illustrates the bending of a tee-iron. The operation differs in no essential respect from that of bending an angle. The bending block is formed so that the web of the tee-iron shall fall into the groove, and the flange rest upon its face. Angles, however, are bent in those blocks as well, one web falling into the groove, the other resting on one side of the top face.

As in angles, so in tees, if a curve of not very quick radius

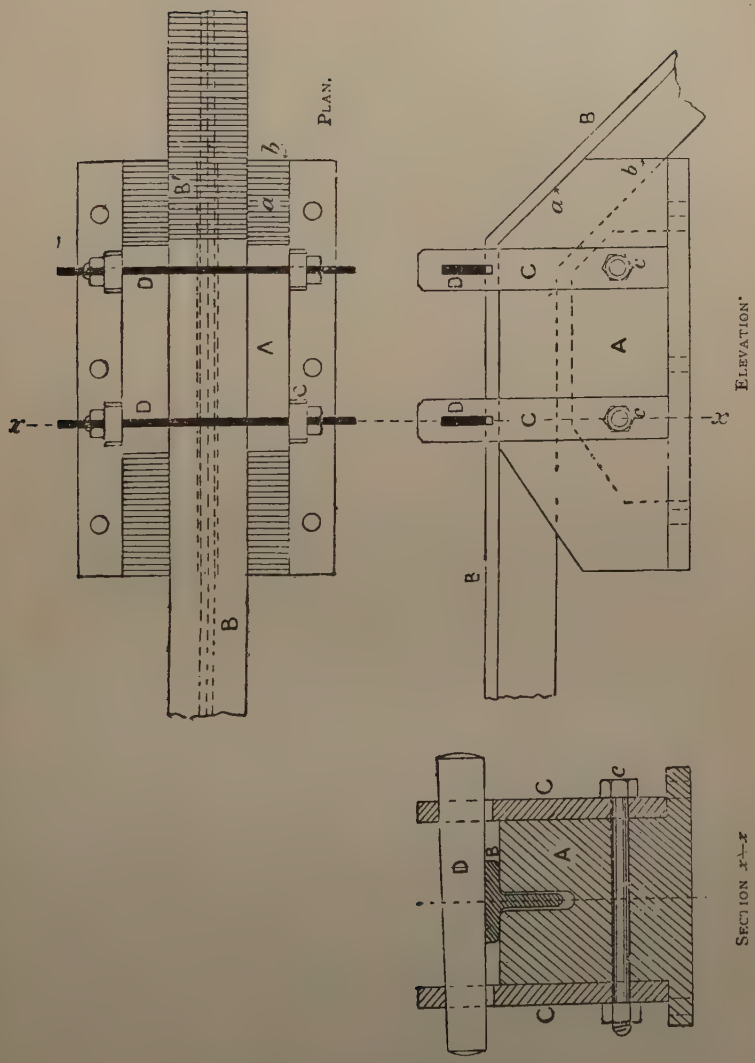


FIG. 149.—PLAN, ELEVATION, AND SECTION.

is being bent, the iron will go round the sweep without cutting; but if a sharp angle is being bent, then the web of the tee must be cut and subsequently welded by the methods just now illustrated.

The preceding figure (Fig. 149) illustrates the method of holding the tee while it is being bent. A is the block, typical of a class made in many modified outlines to suit given classes of work having different angles, &c. B is the tee-iron. It is cottared down upon the block during the process of bending the free end B′ over the angled faces *a* and *b*. Two straps C C, are bolted through holes cast through the body of the block. These straps are pierced with cottar ways, through which the cottars D are driven, bearing down upon the flange of the tee-iron. One or more of these cottars may be used, depending on the length of the work. The block itself is bolted down upon the bending block (not shown), or upon the stand already illustrated.

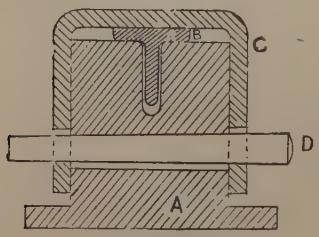


FIG. 150.

In the figure the cottar-ways are cut in straps, C C, bolted to the sides of the block A with bolts, *c*. In Fig. 150 an alternative method of cottaring is shown. A strap C, of 2 in. or $2\frac{1}{2}$ in. in width, is arched over the tee, embracing the sides of the block, and the cottar D passes through it and through a hole cast in the block.

Bending of Rails.—Rails frequently have to be bent to slight curvature. Fig. 151, A, shows a block suitable for bending them against. The block is bolted down to the bending block. The position of the rail in relation to the block is shown dotted at B. The tread of the rail rests upon the face *a*—*a* of the bottom bending block to which A is bolted. The methods of clamping are similar to those previously shown, and need not be repeated.

It is evident, from the illustrations given in this and the articles immediately preceding, that blocks can be designed to bend any sections of iron and steel for regular work, and for any special work. Having made large numbers of them for various purposes, I have given what I consider a fair typical

selection. Channels and H sections are also sometimes bent against blocks, as for the framings of some turntables, for example, and in some constructional ironwork. Fig. 151 may be taken as typical of blocks of this character, the sectional shape of the face being made to suit the section of a given iron. I need give no illustrations of these, but will pass on to another class of bending—that, namely, of flat bars and squares, where blocks of a different type from those yet illustrated are made use of.

Bending of Foundation Ring.—One branch of boiler work is the formation of rings, the principal of which are

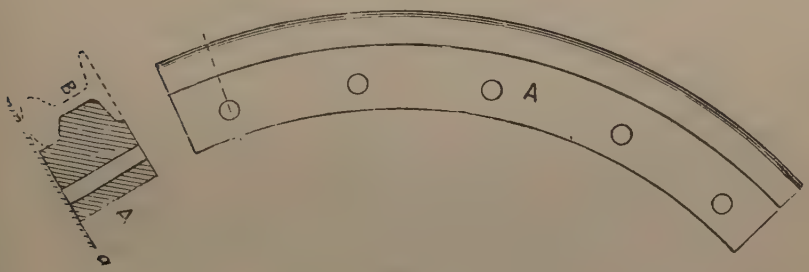


FIG. 151.

foundation rings, and manhole rings. These are bent round blocks of the same shape as the rings, by which large quantities are made uniformly and cheaply.

Fig. 152 illustrates the bending of a foundation ring. I may mention, by the way, that these are sometimes bent in the rolls, but the method shown in the figure is a better one. In this figure, A is the bending block, which is supported upon three pieces of blocking B, shown dotted in plan. The edge *a* is of the same diameter as the inside diameter of the ring, plus a $\frac{1}{4}$ in., or thereabouts, allowance for shrinkage of the hot iron. C is the iron which is being bent. Being heated in the furnace, it is secured first at one end with the clamp *b*. In the figure this is simply a bit of stiff bar iron bent and pinched over the bar C, clipping it upon the outside and taking a pull in the nearest hole, *c*, of which there are several cast in the plate A. The bar C is then pulled round the edge *a*. As it is pulled round other clamps are put over it, as at *d*. The pulling

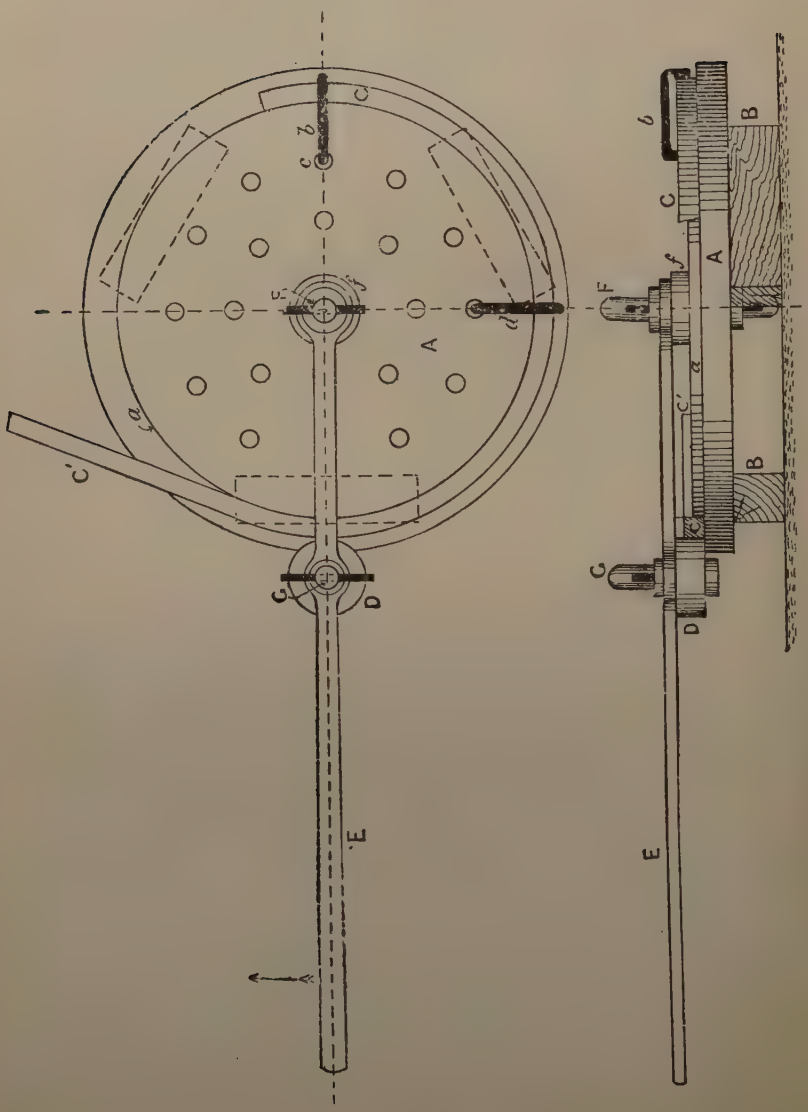


FIG. 152.—PLAN AND ELEVATION.

round is done partly by men pulling at the free end, C′, and partly by means of the roller D and lever E. The latter makes a very perfect and expeditious job. The lever is pivoted in

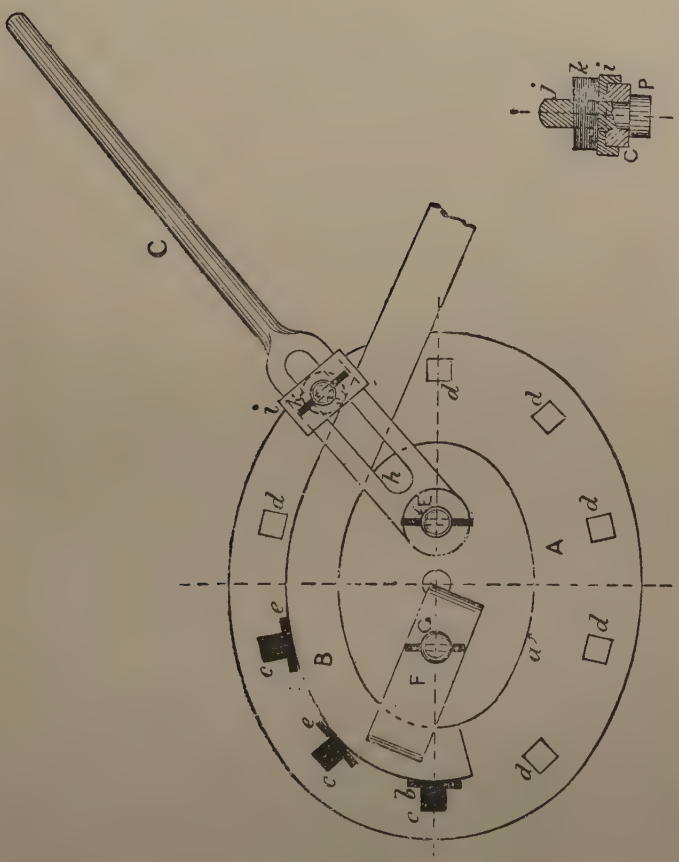


FIG. 153.—PLAN.

the centre of the block A by means of a cottared pin, as shown at F, *f* being a thickness washer to keep E at the correct height. The roller D is pivoted on another cottared pin G, upon which

it turns freely when the handle of E is pulled round, pressing the bar C regularly and neatly against the edge *a*.

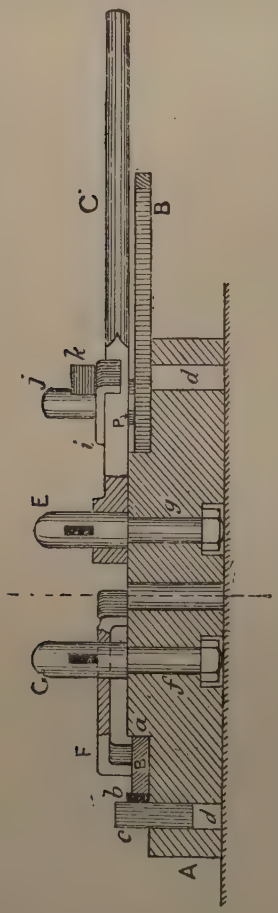


FIG. 153.—SECTIONAL ELEVATION.

In the elevation given in the lower figure, the ring C is shown broken off towards the right hand, and cut off in section at the left hand, in order to permit the shape of the block to be seen clearly.

Bending of Manhole Ring.—Fig. 153 illustrates in plan and sectional elevation respectively the bending of a manhole ring. A is the bending block, the inner edge *a* corresponding with the inner edge of the ring B. The flat bar B, being heated, is wedged at *b*, the wedge having for its point of resistance a bit of square bar *c* put into one of the square holes *d* cast in the block. The wedge prevents the bar from opening outwards. Then the ring is bent round with the lever C and pin P. As it is pulled round, more wedges are inserted at *e e*. When about one-quarter of the ring has been bent, the eye of the lever is shifted from the pivot G in the hole *f* at one focus of the ellipse, over the pivot E in the hole *g* situated at the other focus, and a succeeding portion of the ring B is pulled round. But the ring would pucker up during the bending, due to the quickness of the sweep, but for the provision shown at F. This is a bit of bar arched over, and held down upon the block A and ring B with a cottar driven through the pin G, which prevents any considerable amount of puckering from occurring. The radius of the pin P in the lever C is adjustable, to suit the varying radii of the elliptical ring B. The lever is formed with a slot *h*, and the shank *j*

of the pin P is movable up and down in this. A clip *i* bridges the lever at this part; the shank *j* passes through it, and the cottar *k* fastens the clip and pin fast at any radius in the range of the slot. A section of this part is shown at the right of Fig. 153, p. 143.

Fig. 154 shows the ring completed, in plan and in elevation, the lever being removed, and only the pins *f* and *g* remaining.

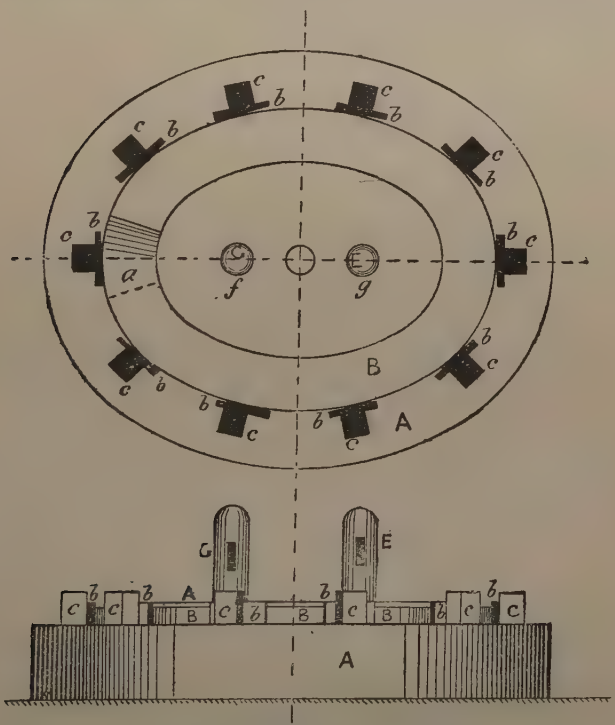


FIG. 154.—PLAN AND ELEVATION.

The overlap of the ring for welding is shown at *a*. The wedges *b* and pins *c* will now be all knocked back, and the ring be removed for welding, after which it will be bent to the curvature of the boiler shell upon a block.

The method of bending by means of a lever and roller illustrated in Figs. 152 and 153 is one in very frequent use

in the boiler shop. It is employed not only for bending bars of rectangular section, but also angles and tees. The typical form of the block is that shown in Fig. 152, but various rigs-up are devised to suit different jobs.

Machine for Bending Angle-Irons.—Figs. 155-158 illustrate an apparatus sometimes employed for bending angles

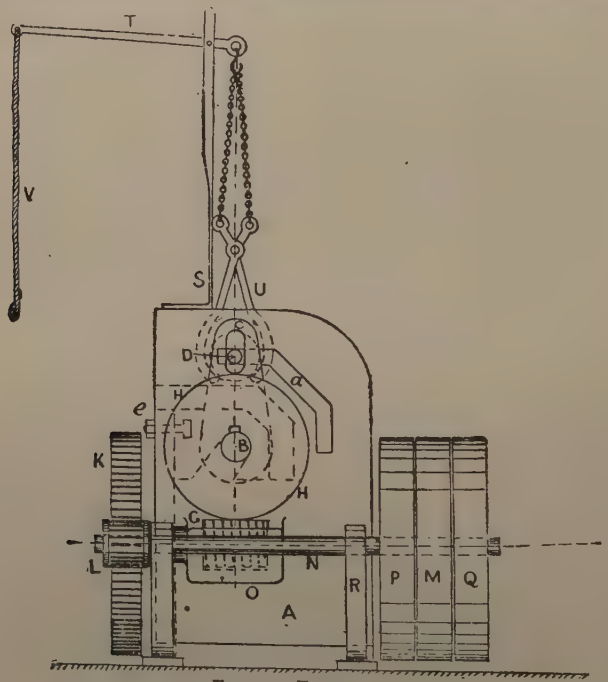


FIG. 155.—ELEVATION.

and tees when a large number have to be bent to the same outline. It is especially useful for bridge and girder work.

In these figures A A are the two cheeks of a massive casting, which forms the main frame of the mechanism. Feet cast upon it receive bolts, for holding it down to a suitable foundation of timber, or of stone or concrete. The two sides are rigidly united by means of a stretcher A'. Holes are cast and bored in the cheeks to receive a stout shaft B, which can be

revolved through a small arc of a circle by means which will be presently described. Upon this shaft two levers C C are keyed. The levers are provided with slot-holes at the smaller—the upper end, Fig. 155. Through these slot-holes a shaft D passes, making a free fit in the slots. It carries a roller, E, bored to fit it, the roller sliding and turning between the cheeks A A.

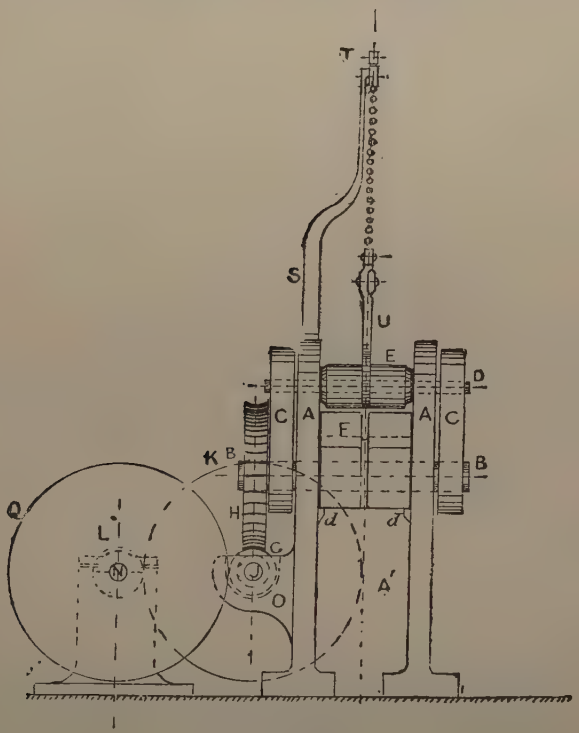


FIG. 156.—END VIEW.

The shaft D fits freely in angular slots, *a*, cast in the cheeks A A. As the levers C pivot round the shaft B, the slots in the levers C permit of movement of the shaft D sufficient to allow it to slide along the angular slots *a a* in the cheeks. Obviously, then, the roller E will have an angular movement imparted to it, corresponding to the form of the slots.

At F there is a cast-iron templet block, shown separately and enlarged in Fig. 158. It is made to fit with chipping strips between the cheeks A A. Several such blocks will be made at different times for a machine of this kind to suit angle-irons or tee-irons bent to various bevels and to various lengths of bevel. No very great variation can be made in the blocks, neither is it necessary in bridge and girder work; but differences can be made equal to the amount of play which the pin D has in the

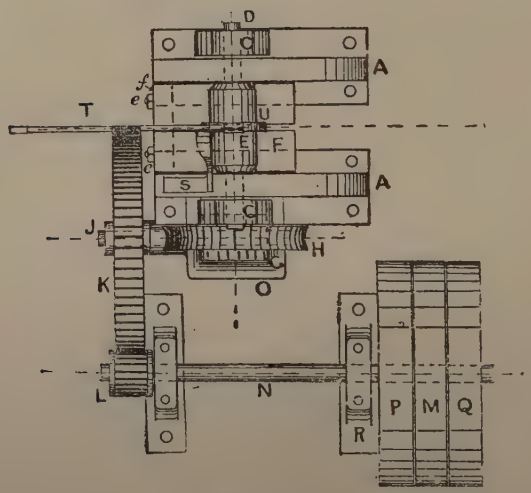


FIG. 157.—PLAN.

slots in C C, and the slack between the pin and the roller E. Rollers of different sizes may also be substituted. It is obvious, therefore, that a piece of red-hot angle or tee squeezed between the templet block F and roller E will receive the exact contour of the block F, upon which it is pressed. And this is the function of the machine—to save the time otherwise spent in finishing to outline and dimensions with hammer and flatter, square and bevel.

The driving power of the machine is as follows:—

Great power is required to press the roller E around the angle-iron. This is obtained by means of worm gear. A worm

G, of coarse pitch, drives the worm wheel H, keyed upon the shaft B. The worm G is keyed upon the shaft J. This carries a spur-wheel K, driven by the pinion L. The pinion is driven by the middle pulley M, keyed upon shaft N. The roller E, therefore, turns slowly, but exercises great pressure. The worm G runs in an oil vessel, O, cast upon the side of A. The machine is reversible, by means of the two loose pulleys P and Q, which carry two belts running in opposite directions. A separate striking-gear, not shown, is fitted to each pulley—one for

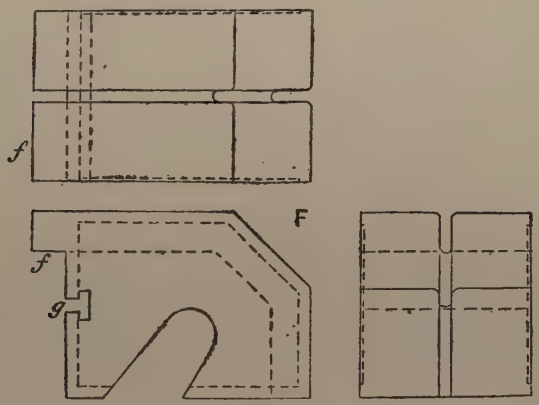


FIG. 158.

driving forward, one for running backwards. The guides for the striking-gear are bolted down upon the caps of the plummer-block R.

In order to free the angles or tees after they have been bent, the roller E must be lifted out. To do this, the pin D must first be drawn out endwise. A special bit of apparatus is rigged up to lift the roller away. A light standard, S, is bolted on top of one cheek A, and a lever pivoted to it. A hook carries a couple of bits of jack chain ; from two other hooks slung in these chains the light clips U depend. When it is required to lift the roller, the lever T is lowered, the clips U placed over the roller, and the lever being lifted by pulling at the rope V, the clips tighten on the roller, and lift it out of its place.

This bending machine obviates the need of welding the

corners of the work. It is, however, not adapted for the highest class of work, which must be done by hand in the manner already described. First the angles have to be made very hot, and then the forcible stretching and compression of the metal makes hollows at the corners. Still, for bridge and girder, and turntable work, in which correct outline and uniformity in the whole series is of more importance than the high

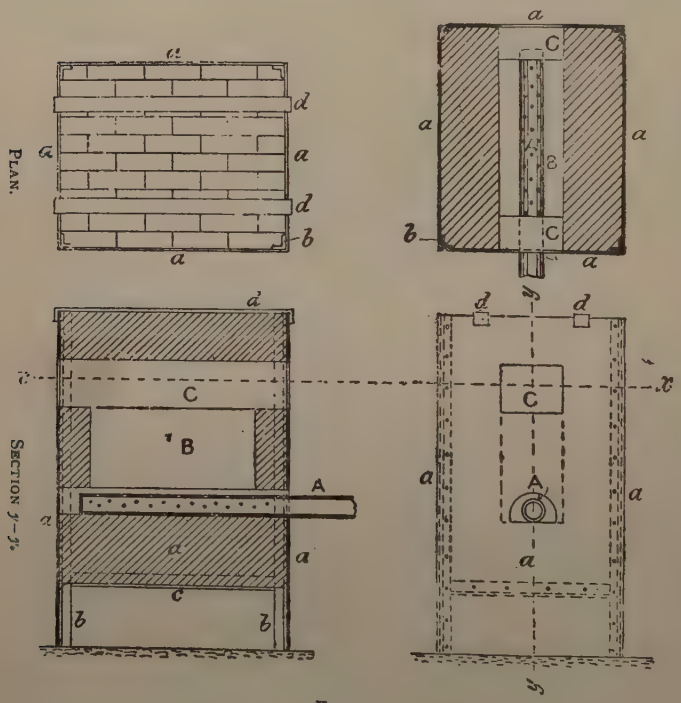


Fig. 159.

strength attainable by good handwork, the machine is very serviceable. Large quantities of angles can be bent all precisely alike and very cheaply. Two angles have to be bent at a time, back to back, and held at the ends with cramps, otherwise they will curl round during bending. It is this tendency to curl and crumple that is corrected by the hammer and flatter during

bending upon a block, which method is not available when bending in this machine.

The templet block F, shown enlarged in Fig. 158, is furnished with a shoulder, *f*, which rests upon the top of the rib A′, Fig. 156, and serves, in conjunction with joggles *d*, and tee-headed bolts *e e*, Fig. 157, fitting in the slot *g*, to sustain the block under the pressure of the roller E. A machine for bending angles and tees is illustrated in Chap. XVII., p. 315.

Furnace for Heating Angles.—A special furnace is used for heating the length of iron that has to be bent. A forge fire is not suitable for so great a length, and a common reverberatory furnace is too large. A miniature reverberatory furnace is therefore rigged up, Fig. 159. It consists of four plates of sheet-iron, *a*, united with angles *b* at the corners. Angles *c* are carried round the lower part near the bottom, to carry the bricks with which the furnace is lined. It is also stayed at the top with two binding straps, *d*. An iron tube, A, passes from side to side in the furnace. It is open at one end to receive a blast-pipe, brought from the shop blast. The other end abuts against the sheet-iron at its end of the furnace. The upper surface is pierced with numerous holes to allow an exit for the blast. Over this pipe, in the space B, a coke fire is built. Over the coke, in the space C, the angle or tee is thrust. The blast passes up through the coke, and the heat strikes on the bottom face of the iron, and is deflected down upon its top and side faces from the white hot bricks above and around, so that there is uniform heat, no contact of fuel with iron, and the smith can easily watch the progress of the heat from the outside of the opening C.

CHAPTER IX.

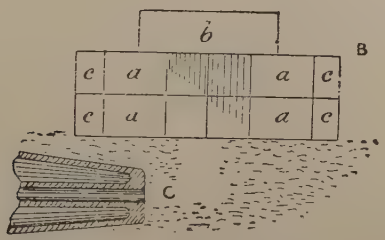
WELDING.

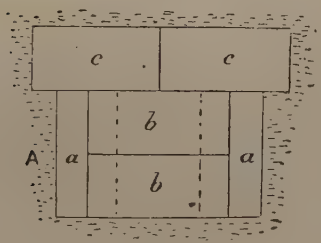
Differences in Welding as done by Smiths and by Boiler-makers.—Making Hollow Fires with Bricks.—The Heat for Welding.—The Scarfed Form of Weld.—Manhole Ring.—Firehole Ring.—The Glut Form of Weld.—Foundation Ring.—Rigs-up for same.—Angle-iron Rings.—Rigs-up for same.—Angle-iron Frames.—Scarfed Joints.—Rigs-up.—Burrs.—Glut Joints.—Welds in Tubes.—Lap Welds.—Glut Welds.—Mandrels.—Portable Furnace.—Portable Anvil.—Rig-up for Tubes.

Difference in Welding, as done by Smiths and by Boiler-makers.—The welding done by boiler-makers differs in the main in many respects from that done by engine smiths. Speaking generally, the difference consists in this: that the boiler-maker has to operate on larger surfaces than the smith, and that he has to deal very much with plates and sections which do not come within the range of ordinary smith's work, and which demands the use of methods more elaborate than those involved in the making of plain scarfed and butt joints, between bars and rods. Plain scarfed joints are those mostly used by smiths; but the boiler-maker employs butt welds and gluts quite as commonly. Moreover, owing to the large surfaces which frequently have to be united at a single heat, the boiler-maker has to build special fires, and also use special rigs-up for holding the work in position during welding. These operations are very interesting, and as they have never, to my knowledge, been illustrated and described, I propose devoting two or three chapters to this subject.

Before, however, saying anything about special welds, I will, once for all, clear the way and avoid repetition by describing the methods which are applicable to welds in general. My remarks will have reference first to *the fire*, and second to *the heat*.

Making Hollow Fires with Bricks.—There is an art in making up a fire for welding. It should really be, in principle, a little reverberatory furnace—in this sense, that the less the fuel comes in actual contact with the work the better.





PLAN.

FIG. 160.

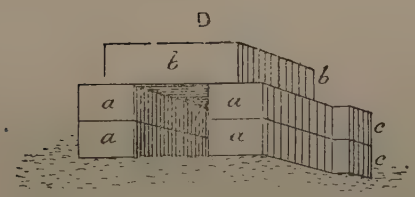


FIG. 161.

Actually, indeed, it should not come into contact with the surfaces to be welded at all. Hence fire-bricks and sections of iron are commonly used on the boiler-maker's forge to enclose

the work which is being heated. I shall show some arrangements of this kind, and one or two others will follow in later chapters. Speaking generally—Figs. 160-161—the bricks are arranged around and over the tuyere opening, enclosing the portion of the work which has to be raised to welding heat, and coke or small coal covers over the parts adjacent which have not to be heated. Fig. 160 is an attempt to illustrate the typical arrangement of bricks enclosing a welding fire. A is a plan view, B a front view showing the nozzle of the tuyere C in section, and Fig. 161 is a perspective view. In these figures, *a*, *a*, *a*, *a*, are four bricks which form the furnace sides, covered with two bricks, *b*, *b*, to form the roof, and backed by four bricks, *c*, *c*, *c*, *c*, to form the closed end of the furnace. This is rather a small structure, but larger ones are readily made by other arrangements of the bricks in conjunction with sheet-iron—as, for instance, two or three bricks are clamped together, end to end, with a piece of sheet-iron turned down at the ends to form a long roof covering, and so forth, any desired arrangement being improvised for a given job. There is, therefore, only one opening, that in the front, into which the work is thrust. Small coal is sometimes heaped around the bricks, though not always. But a good clear hot coke fire is got underneath the opening on the bed of the forge, and round the mouth, and the bricks are well heated before the work is thrust in. The structure is arranged so that the tuyere opening shall come nearly under the work, as shown at C, to ensure the blast taking full effect upon it, so that the welding portion is enclosed in a hollow fire, the roof and sides of which are enclosed with bricks, and the intense heat retained in these is deflected down upon the work enclosed on all other sides with incandescent fuel.

Fig. 162 shows another arrangement of bricks enclosing two angles A and B, the ends of which have to be united with a scarf weld. The bricks—two or more according to the size of angle—arch over the ends, and those portions of the angle which lie outside are well supported with the small coal.

Fig. 163 illustrates a form of hollow fire in which the mouth of the opening is closed with a piece of plate, A, which is removed with the point of the poker, inserted in the hole *a*, when the smith wants to examine the progress of the heat. The bricks in this illustration are not visible, being heaped over with small coal, as noted just now. The tee-iron B, in the fire, being too long to be supported entirely on the forge, is partly sustained by

the stand and legs C, already shown in Fig. 124, page 116. These examples will be sufficient to illustrate the general methods of obtaining the welding heat on angles and tees.

From time to time the smith pokes out a little opening in the fuel, and judges, partly by sight, partly by feeling the metal with the point of the poker, how the heat is proceeding. He will do this several times before the precise white heat and soft and pasty condition of surface suitable for welding is attained. Then the work is removed at once from the fire, clean, and with scarcely a trace of fuel adherent, and, being rapidly brushed, is ready for welding.

As regards the use of sand for fluxing, the importance of this is often over-estimated. I have seen plenty of iron welds made without a particle of sand having been used. If a clean surface is preserved by the means just described, sand may often be dispensed with. But when work is being done, the surfaces of which are already brought close together before they are put into the fire for the final welding heat, as is the case in many instances, then it is necessary to use sand. This is thrown upon the work in the fire while it is being raised to the welding heat. Three or four such separate applications of sand may thus be made before the work is withdrawn. Also that portion of the anvil or of the block, as the case may be, upon which the welding has to be done, is strewn with sand before the work is laid upon it.

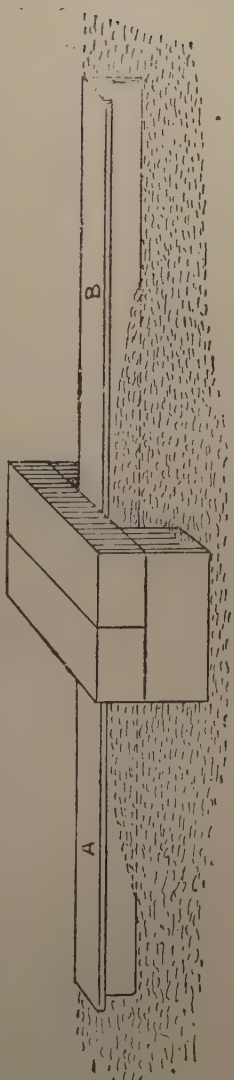


FIG. 162.

The Heat for Welding.—As regards the heat for welding, much has been written about this, but after all there is nothing which can enable one to form an accurate idea of heats

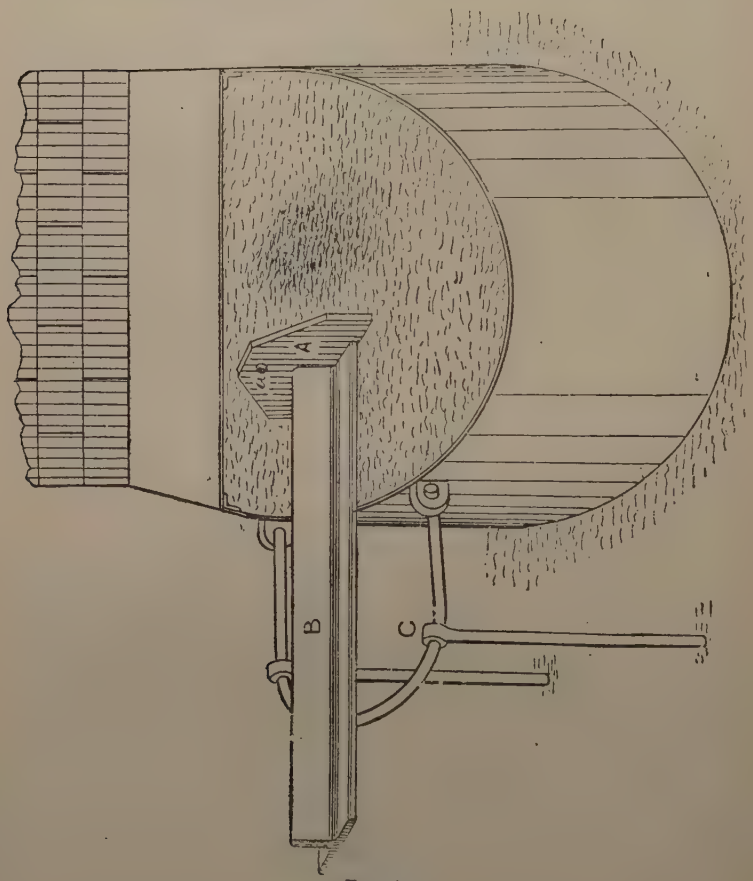


FIG. 163.

save actual observation and practice at the forge. A full, dazzling white heat is the welding heat for iron; a lesser temperature—a bright heat, less dazzling—is suitable for steel. In

fact, for steel, the lowest heat at which the surfaces can be united should be chosen, because to overheat steel is ruinous to its tenacity and strength. The smith judges of the welding heat in each case partly by appearance, but also by the sense of touch by the poker of the semi-pasty condition which is requisite to the union of surfaces.

Tables VII. and VIII. following will show how wide ranges of temperature are estimated more or less approximately in degrees Fahr. It may be consulted not only for heats for welding and forging, but also for tempering, for fusible plugs, and for general pyrometric purposes :—

Table VII.

To Estimate Temperature roughly by the Appearance of Metal.

Appearance.	Temp. Fahr.	Appearance.	Temp. Fahr.
Red, just visible	977°	Orange, deep .	2010°
,, dull . .	1290°	,, clear .	2190°
,, cherry, dull	1470°	White heat .	2370°
,, ,, full	1650°	,, bright	2550°
,, ,, clear	1830°	,, dazzling	2730°

Table VIII.

To Estimate Exact Temperatures by the Fusion of Substances.

Substance.	Temp. Fahr.	Metal.	Temp. Fahr.	Metal.	Temp. Fahr.
Tallow .	92°	Bismuth .	518°	Silver, pure .	1830°
Spermaceti	120°	Lead . .	630°	Gold Coin . .	2156°
Wax, white	154°	Zinc . .	793°	Iron, Cast, med.	2010°
Sulphur .	239°	Antimony	810°	Steel . . .	2550°
Tin . .	455°	Brass . .	1650°	Wrought Iron	2910°

The Scarfed Form of Weld. — The plain scarfed joint is adopted chiefly in work of plain rectangular section, as in manhole, firehole, and foundation rings. Neither is that alone used here, but sometimes the glut form of weld is adapted in such plain work.

Manhole Ring.—About the simplest illustration of scarf welding which I can select is the manhole ring, the bending of which was illustrated in Figs. 153, 154, pp. 143-145. The ends of the ring as they appear when ready for welding are shown in Fig. 164. They are slightly upset—that is, the ends are thickened or dumped up with hammer-blows before being welded, and this is properly done before the bending is performed. If the ends were not thickened thus, the effect of welding would be to make the jointed portion slightly thinner than the adjacent portions, the hammer-blows thinning it down at that part. Hence, all ends which have to be welded are, except in some few special cases, thickened or upset in this fashion.

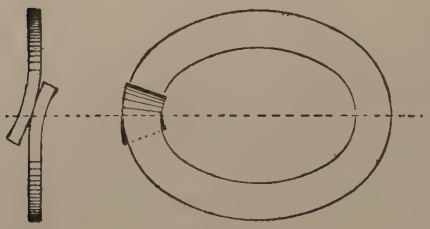


FIG. 164.

FIG. 165.

After the welding is accomplished, the ring is brought to uniform section, and smoothed at the locality of the weld with the flatters, and is afterwards bent to the curvature of the boiler shell upon a concave cast-iron block, Fig. 165.

Firehole Ring.—The firehole ring, Fig. 166, may be welded also with a scarfed joint. But as a rule thick rings of this and similar types are welded with V-shaped gluts, in the way to be described immediately. After welding it is bent to the curvature of the boiler upon a block, Fig. 167, similar in shape to Fig. 165. But the ring being thicker, is set down in place not only with the hammer, but also with screw pressure, the screw A being tapped into the block, and a bar B tightened down upon the ring C, by means of the nut.

In these small rings, which are tolerably rigid, there is no need of any special rig-up for the purpose of preserving their diameter correct during welding. But in all rings of large size provision has to be made for keeping their size unaltered during the operation of welding. This is, in fact, one of the tasks wherein the difference between the careful and the unreliable workman is apparent. Much care is required to get rings of exact diameter, because there is not only the effect of alteration due to welding to be guarded against, but there is also the distortion due to heating to be taken account of. And after a ring is welded it is impossible to make any material alteration in its diameter by setting inwards or outwards. Hence all rings of large size, of whatever section, that are required to be of exact dimensions, are secured during welding with clips of some form or other. For a similar reason all angle-iron framings are held during the welding of the corners, first to keep them of the correct shape, square or otherwise, and then to keep them of the correct size across. Some of these fastenings will come in for illustration in the examples to follow.

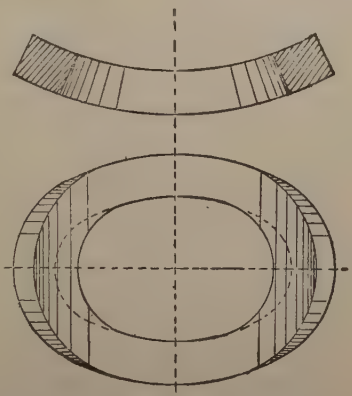


FIG. 166.

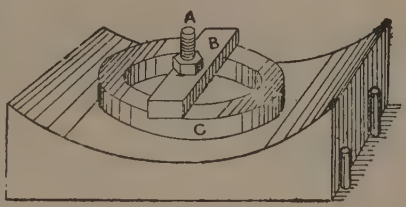


FIG. 167.

The Glut Form of Weld—Foundation Ring.—Figs. 168–171 illustrate the welding of a foundation ring with a vee or "glut" form of weld. This is a very common and a very safe weld, when properly made. In a thick ring it is double; but when employed in plates bent into tubes, and in angles, a single glut strip only is used.

The foundation ring is prepared first as shown in Fig. 168—that is, the ends are upset by hammering, before the ring is bent. The ends are upset, either in the plane of bending, as shown in Fig. 168, or at right angles therewith, as seen in Fig. 171. Then just the ends, say for a length of three or four inches, are hammered to the curvature of the ring before the entire ring is bent, for the reason given in connection with Fig. 140, p. 131. It is at this stage that the bar is seen in Fig. 168. The ring is then bent to a complete circle like Fig. 169, either upon a templet block like Fig. 152, p. 142, or in the bending rolls. The apices of the two vee'd ends should nearly meet, as shown.

FIG. 168.

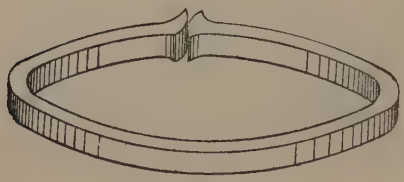


FIG. 169.

Rigs-up for same.—Various pieces of apparatus may be devised for holding rings and frames, and I shall show alternate methods in connection with different jobs, so that it will be understood that any one which I illustrate is not the only one which might be, or is used, but different men would adopt different methods.

Now, in the case of this ring, it is necessary that it shall be turned about rapidly and easily to get at its different faces during a heat. In this case, therefore, the rig-up may consist of a swivelling arrangement. Two flat bars (Fig. 170) A, B, one, A, furnished with trunnions, are bolted on opposite faces of the ring C, and serve to keep it in a true plane, and also from opening outwards. The trunnions permit of the turning about or swivelling of the ring. The trunnions are supported in sling loops D, which depend from the forge crane by which the work is swung between forge and anvil. I need not illustrate the crane, but only the appliances used with it on this and on many similar jobs.

From the cross-beam E the slings D D depend. The beam is supported in the wall jib-crane, which is an adjunct of the

forge. In the figure, F F are the sides of the jib, seen in section. These run out horizontally, and the jib is pivoted at the wall, so that it describes an arc of a circle. G G are the wheels of the jinny J, the jinny being traversed along the jib

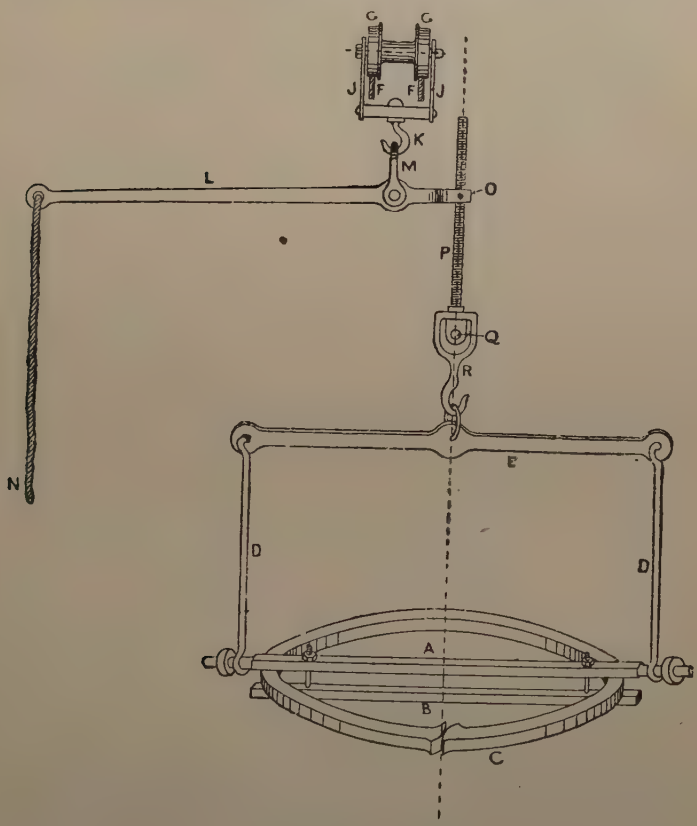


FIG. 170.

from end to end. From the hook K, which is capable of a swivelling movement in the jinny, the appliance shown in the figure is suspended. It comprises an unequal-armed lever L,

pivoted in the loop M, and pulled down by means of the rope N, within reach of the workman's hand. In the short end of the lever, which is forked, a nut O is pivoted, and through this runs the screw P, which is turned in the nut by means of the eye Q swivelling in the loop of the hook R. The screw P, therefore, is for adjustment of the ring or other piece of work to a suitable average or mean height, while the lever L is for lifting and lowering it between forge and anvil. By means of this appliance and rig-up the ring can be lifted from the forge, slung round, and lowered upon the anvil in two or three

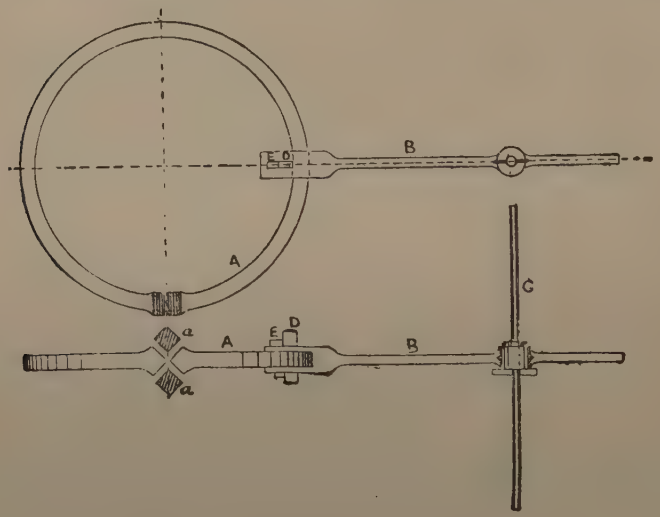


FIG. 171.

seconds while at a welding heat. Owing to the leverage afforded, the labour of moving it is no more than one man can accomplish.

This is a good method of rig-up for large heavy rings. For lighter ones the plan shown in Figs. 171 and 172 is also good. The latter figure is simply a separate enlarged view of the appliance shown attached to the ring in Fig. 171. In these figures A is the ring, B is a gripping bar for holding it fast, and C a lever for turning it about, the latter being held by

the striker. B is provided with a forked end to grip the ring. It is secured to the ring with a wedge D, bearing against a gib E. It is therefore quickly secured and quickly released. The lever C passes through a boss in B, in which it is secured with a wedge F. In this instance there is no provision for keeping the ring from opening out during welding, as there is in the previous figure. But it is not essential to bind foundation rings thus, because being made of bar of stout section, say from $1\frac{3}{4}$ in. to $2\frac{1}{2}$ in. square, they are very rigid in themselves. But in angles

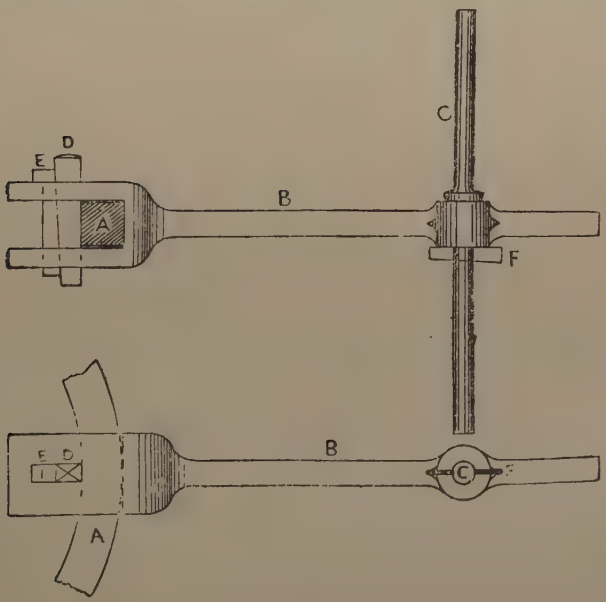


FIG. 172.

it is almost always necessary to use a clip of some kind, as we shall see presently. It will be noted also that there is a difference in the position of the vees in Figs. 169, 170, and in Fig. 171. In the former figures the vees are inside and out; in the latter they are on top and bottom. These are simply alternative methods, but the latter is preferable.

The welding is done in two heats, one for each glut. A square bar, which may be a couple of feet long, is heated

simultaneously with the upset ends of the ring. When at the welding heat the ring is taken from the fire and laid upon the forge, and the heated end of the square bar hammered into the inner vee, so making the joint. No finishing is done; but the free or porter end of the bar—that, namely, which does not form the actual weld—is cut off with the hot set, and the ring and bar are both returned to the fire for the second heat.

To form the second weld the interior of the ring is laid over a convex block upon the anvil, or when the ring is too large to permit of that, against a convex block laid horizontally upon the shop bending block, and the second glut is welded in and the free end of the bar cut off. At the same heat the finishing is done, consisting of smoothing the flat faces and the concave and convex curves respectively upon the anvil, and upon blocks curved suitably. In the case of Fig. 171 there is no bother with convex blocks, but the gluts are welded in both top and bottom vees on the anvil. These are shown in section at *a a*, in the positions which they occupy in relation to the vees in the ring previously to welding. The vees and gluts are very slightly exaggerated out of proportion to the ring, the better to show their forms. Sometimes triangular glut pieces, or pieces of oblong section instead of square, are welded in. These are matters of varying detail.

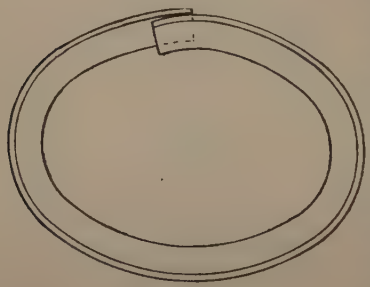


Fig. 173.

Angle-Iron Rings.—The vee form of weld is used for angle-iron rings, chiefly for those having sections relatively heavy in proportion to their diameters. Light rings, however, are usually welded with a lap-joint. Thus the light angle ring surrounding a wrought-iron manhole cover will be usually welded with a lap, while the heavy ring surrounding the uptake of a boiler will be welded with a vee or glut. The reason why lap welds are not suitable for angles of large section is because it is difficult to get a uniform heat on the inner faces without unduly heating the outer. Beyond, therefore, sizes of from $1\frac{1}{2}$ in. to 2 in., angles are welded with gluts. Fig. 173, the

stiffening ring for a manhole cover, shows how the lap-joint is made for an angle of small section. Very little upsetting of the ends can be attempted. The length of the lap may be from $1\frac{1}{2}$ in. to 2 in. If the ring is very small, it is better to make the joint at one end of the ellipse. The welding is done in two heats: one for the flange, and one for the web, the flange being done upon a level block, and the web being done upon a curved block, either convex or concave, as happens to be most convenient for any particular job.

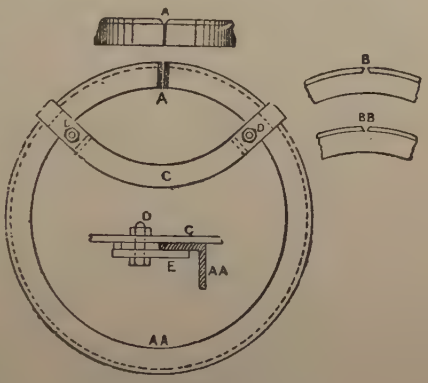


FIG. 174.

The vee welds would be made as shown in Fig. 174, in two separate heats, one on the flat flange outside, A, and one on the vertical web inside, B, if the ring is of sufficient diameter to permit of the use of the hammer and flatter; but on the outside, BB, if the ring is small.

Rigs-up for same.—No special rigs-up are used for manipulating a stiff angle-iron ring of small diameter. It is held simply in the tongs, or with a porter like Fig. 175, and its

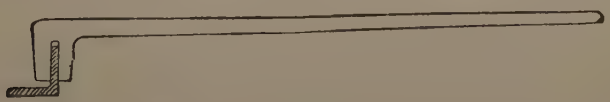


FIG. 175.

own rigidity keeps it from spreading outwards during welding. But a light ring has to be kept in one position with a stretcher bar. Fig. 174 shows a common rig-up of this kind. A piece of plate C, turned down at the ends, is made to clip the ring AA, and is held firmly in that position with a couple of bolts D, D, clamping two small washer-like pieces of plate E against the

opposite faces of the flat flange. One such fastening is shown enlarged in section about the centre of the ring.

While on the subject of welding angle-iron rings, I may as well just note the completion of the work of their formation. The finishing with the flatters need not be more than alluded to, as that is done after all welding operations. The work is laid upon flat or curved surfaces the while, according as the surfaces to be trued are flat or curved, and a neat smooth finish, and a uniform thickness over the welded parts, and the parts immediately adjacent, are thereby secured. But in rings of this kind, and, indeed, in rings of other sections made with flat iron or with tees, there is, notwithstanding all care, some difficulty experienced in getting a number of welded rings all precisely alike in diameter. This is not practicable unless some slight adjustment is done subsequently to welding. This is one use of the cone illustrated in Fig. 132, p. 122. The boiler-maker aims at welding up rings a trifle small rather than large, because it is much easier to open them out a little than to close them. The rings being a trifle under size, it is easy to get them red hot, and open them out by hammering them down over the cone to a position corresponding with the exact diameter required, making such allowance as is necessary for the shrinkage of the hot metal, and if the difference is but slight, then there is no need even to heat the rings, but they can be set down cold.

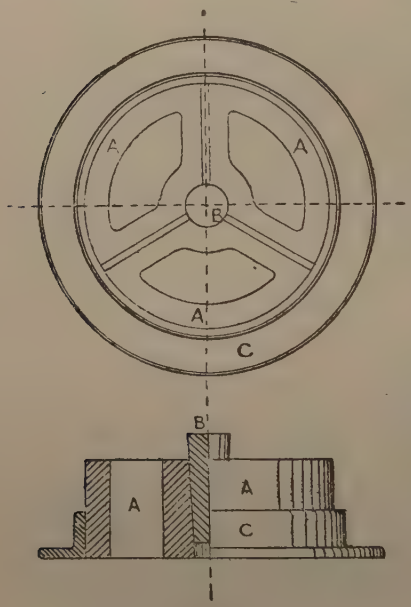


FIG. 176.

A drawback to very accurate work exists in the slightly

conical form then imparted to the interior of the ring. It is so slight, however, as to be quite inappreciable in shallow rings, and may be still further minimised by turning the ring over, and setting out each side in turn; but for deep rings and for very accurate work, and for large numbers, an appliance like Fig. 176 is used. This consists of three segmental cast-iron blocks A, and a central pin B. The blocks are inserted within the ring C to be corrected, and are forced outwards by driving in the pin. In this way absolute uniformity can be secured in any number of similar rings, and the internal portion will be perfectly parallel. Such blocks will only serve for rings of identical diameter; but they are cheaply made, and large numbers of them of different sizes will be used and kept in stock in a boiler-shop.

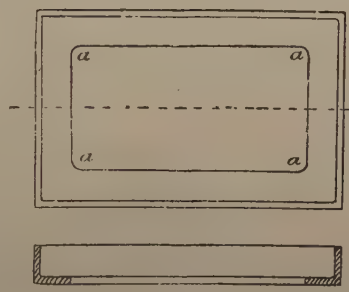


FIG. 177.

Angle-Iron Frames.—I will now pass on to the welding up of angles into rectangular and bevelled forms, the bending of which was described in pp. 135-140. This work admits of considerable variation in practice, and I will try to cover most of the ground, the subject being of much practical importance, and requiring a fair amount of skill and care.

FIG. 178.

Scarfed Joints.—The corners of angles are generally welded by modifications of the lap or scarf joint, and by means of gluts and stick-in pieces. I cannot make any convenient division of this subject, but must just take the cases of external and internal joints as I did when describing the bending of corners.

Figs. 177, 178, and Fig. 191 illustrate the commonest bendings which occur in angles and tees. These particular figures represent the diaphragms used in box girders, Fig. 177 being employed when there are no interior uniting angles, Fig. 178 when there are; and, of course, in carrying angle-irons around plated work, bending at right angles and at angles of 45° or angles greater or less than 45° occur. The same bendings occur, too, in stiffeners made of angle and tee. Further, bendings often take place with the flat web on the exterior, as at A A in Fig. 191. The welds are made in the various following ways :—

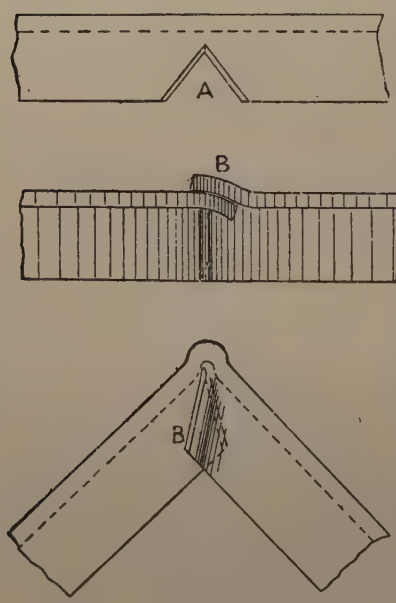


Fig. 179.

Figs. 179-186 illustrate various forms of lap or scarf-joint. Fig. 179 is a square corner, Fig. 180 a diagonal corner, as used for diaphragms, stiffeners, and ends passing over angle-irons. In each case the web is cut as shown in the plan views above, at A; the ends are slightly upset, and turned upwards and downwards into the position shown in the plans and elevations below, B, at which stage they are put into the fire to receive the welding heat. The cut edge which is lowermost is not, however, necessarily hammered down; but all the bending or scarfing may be imparted to the upper one.

In raising the angles to the welding heat a brick is placed over the scarfed portion to prevent the contact of fuel therewith, Fig. 181, A. The under face of the flange is set over a clear hollow fire, and the top face is quite protected by the brick, A, which is supported at one end on the vertical flange, and

at the other on coke. The angle is surrounded and enclosed in the vicinity of the weld with burning coke, as illustrated. The welding portion is, therefore, enclosed in a miniature hollow

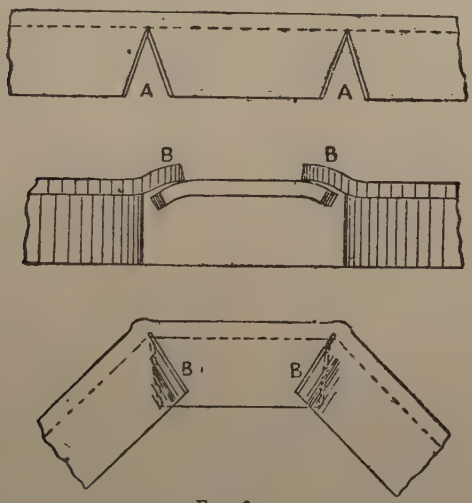


FIG. 180.

furnace, and no fuel touches it to foul its surface. The smith tries the surface with the point of the poker from time to time, and occasionally dusts a little sand over the scarf, until it is ready to be taken from the fire.

Rigs-up.—The welding may be done upon a block, Fig. 182, the angle being clipped against the sides of the block, as shown, as in the operation of bending. But this does not admit of rapid turning about for working and finishing the various faces quickly. Hence the better method is to rig up the apparatus shown in Fig. 183. The strap A, the bolts B, B, and

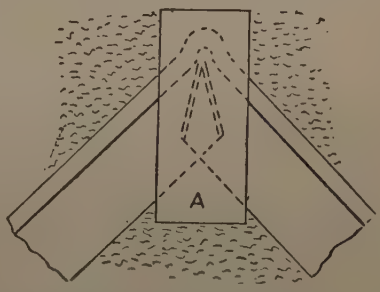


FIG. 181.

washers underneath hold the sides of the angle in an invariable position while being turned about with the tongs upon and

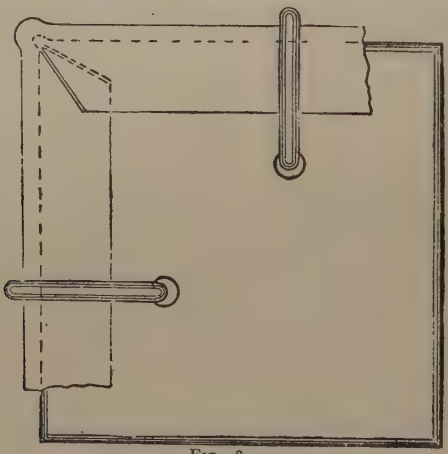


FIG. 182.

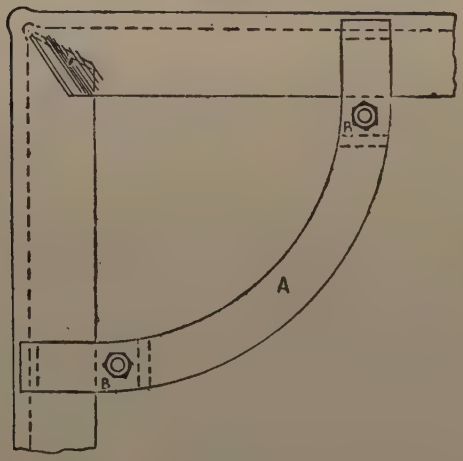


FIG. 183.

against the bending blocks on the anvil. The ends of the strap A are also frequently turned down to embrace the outside faces of the angles, as in Fig. 174, p. 165.

For light angles, the tongs are used for handling about. But for heavy angles, the forked porter shown in Fig. 175,

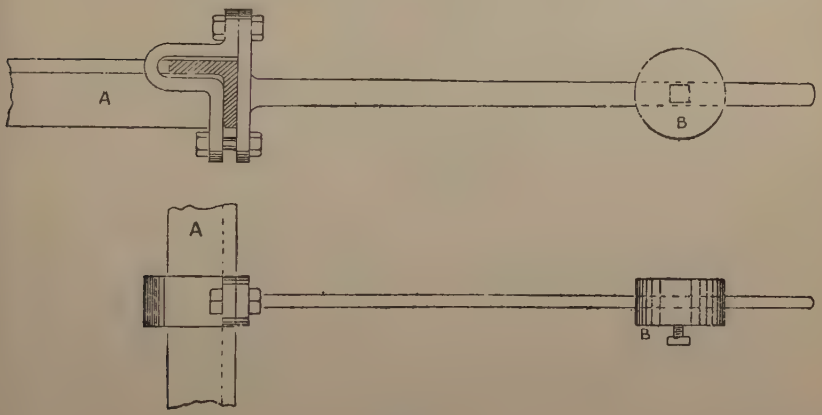


Fig. 184.

p. 165, is employed. Or, better than this, the appliance shown in Fig. 184 is made to clip the angle A, slung in the crane-chain, and provided with any suitable adjustable counterbalance weight B, to balance the weight of the angle. This appliance is used for framings in course of welding up.

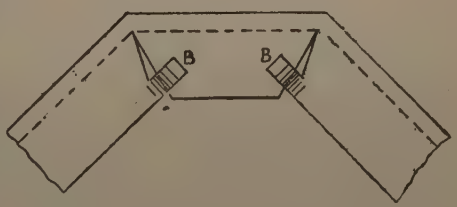


Fig. 185.

After the welding heat is reached, and the angle taken from the fire, a few light blows with the hand-hammer, followed by the sledge, make and consolidate the weld. After this the rest is a matter of finishing and smoothing with the flatter. Note that one effect of having an overlapping

mass of metal for welding in excess of that in the actual section of the web of the angle-iron is to impart a good hollow, Fig. 177, *a a*, to the inner corner, instead of a keen angle. This is very important as affecting the strength of the corner. All corners are, or should be, finished in this manner.

Burrs.—Another form of weld-joint, shown in Fig. 185, though rather peculiar, is yet very common in angle-iron work where the angles are obtuse, as in Fig. 178. It is made as follows:—The web is notched as in the previous examples, but an inner piece is cut away and removed, leaving an open space, Fig. 185, A. The length B is then welded over, being lapped as shown in the lower part of the figure, and the open space is afterwards filled up with a "burr" or punching, stuck in and welded into it, Fig. 186. One, two, or more burrs, *a a*, may be used as required. When all is finished with the flatter, the joint is good and smooth. This practice of welding in burrs is very common in many joints, and also for filling up cracks. One of these burrs or punchings is shown enlarged below in Fig. 186, *a*, ready to be welded into the plate *b*.

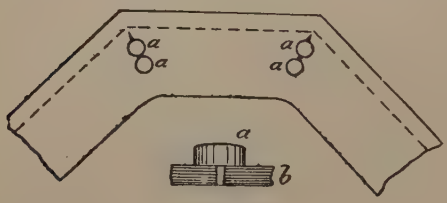
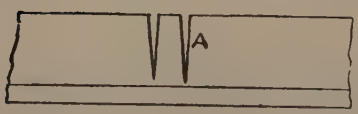


FIG. 186.



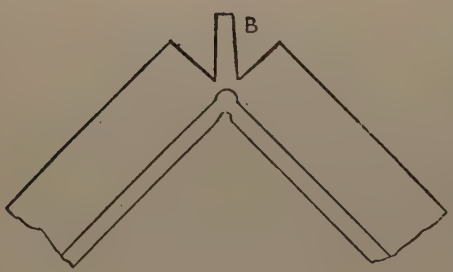


FIG. 187.

Glut Joints.—The method of welding external corners is as follows:—The flat of the angle-iron is notched, Fig. 187, A,

as already noted, and the bending of the angle opens out the notch in the manner shown in Fig. 187, B. This has to be filled up with a glut. The corner is heated in one forge fire, covered over with a brick in the manner already described, and the glut is heated in another fire. Then they are taken out simultaneously, and welded in the manner shown in Fig. 188, A being the notched angle, B being the glut in place, having a porter-bar for the mate to hold it by. A few blows consolidate the weld, after which the porter-bar is cut off and the edges of the glut dressed round with the hot-set, and the joint faces

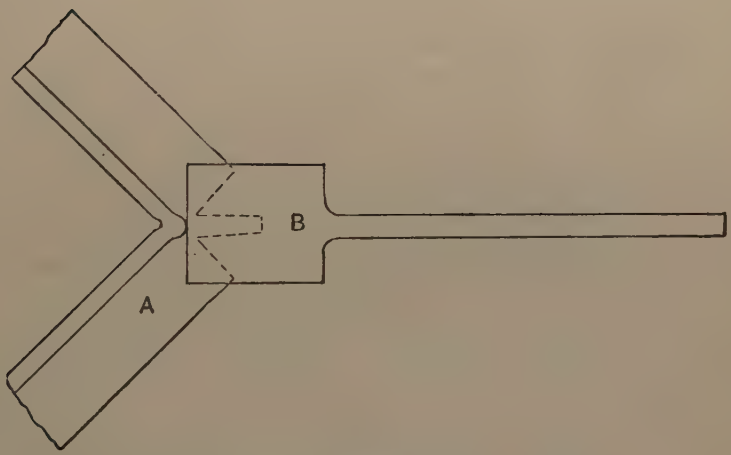


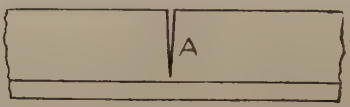
FIG. 188.

finished with the flatter. The original thickness of the glut piece is, of course, rather greater than that of the web of the angle, to allow for finishing off.

The advantage of having a middle tongue on the cut web is obvious on a comparison of Figs. 187 and 188 with Fig. 189. The latter figure shows how wide a gap there would be if the angle were simply divided once at A in the latter figure instead of twice at A in Fig. 187. In Fig. 189 there is a wide gap, in Fig. 187 two relatively narrow gaps. The latter shows, therefore, the mode of division generally adopted.

The welding of tees is done by the same methods as that of angles, the flat web being cut and welded, and the vertical web being bent.

When there is more than one corner to be welded, as in frames, and when it is necessary that over-all dimensions should



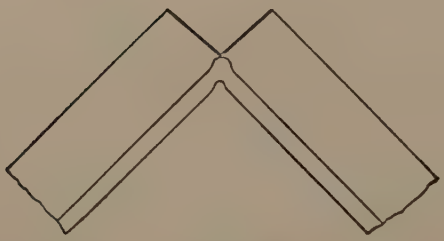


FIG. 189.

be accurately adhered to, then it is necessary to rig up some apparatus to preserve the sides in their correct positions. The usual methods of doing so are shown in Figs. 190, 191.

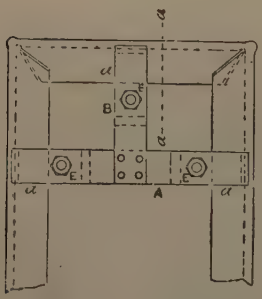


FIG. 190.

In Fig. 190 there are two straps, A and B, riveted together. The ends of these clip the angle at *a a* by means of washers C, thickness bits D, and bolts E; so that the angle cannot be distorted out of shape or dimensions during the welding of the corners.

Fig. 191 illustrates another mode of obtaining security. In this there are interior and exterior bendings of the angle, and

while the exterior welds at A A would be done with a clip like that shown in Fig. 190, the interior B B had better be done with a long strap C, embracing a considerable portion of the

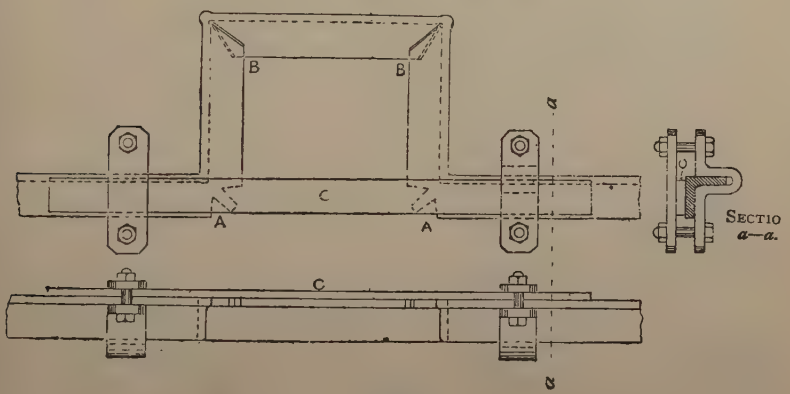


Fig. 191.

straight length of the angle. The method of clipping the angle is shown clearly in the views, so that verbal explanation is unnecessary.

Welds in Tubes.—The foregoing have all been examples of short welds. But the same types of joint are made in the case of welds of considerable length. Thus, fire-boxes and cross-tubes are welded up in lengths of several feet by both lap, and glut, or vee welds. In these cases, a heat of a few inches is done at a time, the joint being thus made in detail.

I do not know which is the better form of joint for tubes, or whether there is any appreciable difference. I have mostly seen the vee form done, and should therefore be inclined to give the preference to that. But I will describe the formation of both.

Lap Welds.—In the formation of a lap-welded tube, the edges of the plate are upset or thickened, the plate bent round until the thickened edges lap sufficiently, and then successive heats, usually of from 6 in. to 8 in., are taken, and the corresponding welds made over a suitable block A, Fig. 192.

A form of joint which is a compromise between a lap and a butt joint is illustrated in its first stage in Fig. 193. The

end *a* is turned around to butt against the inner face of the end *b*, and then *b* is hammered against the end of *a* and also over its outside face. At the welding heat, the end *a* becomes pressed into and amalgamated with *b*.

Glut Welds.—Figs. 194, 195 illustrate the plain glut and the vee form of glut weld respectively. In the first, Fig. 194, the ends of the tube are brought nearly together. The glut is a piece of flat bar, *a*, and the figure shows it in the position just ready

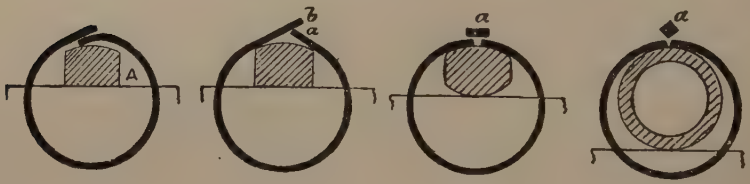


FIG. 192. FIG. 193. FIG. 194. FIG. 195.

for welding. In a thin tube the fact that the abutting sides are sloped, and the sides of the glut are square, makes no difference. At the welding heat the strips and the edges of the plate become amalgamated into one another, being hammered into a solid mass. Fig. 195 shows a vee glut. The slope of the sides of the glut piece *a* approximates to that of the cut edges of the plate when rolled.

Fig. 196 shows a glut welded internally, as is most convient in large shells, just as the external glut is more easily done in the case of small tubes. In this Fig., A is a block of iron hollowed into a concave form on the top face to the curve of the shell.

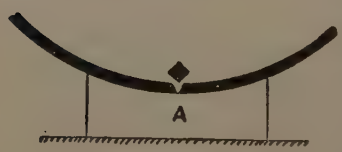


FIG. 196.

The glut strips used are generally of rectangular form laid flatwise, as in Fig. 194; or edgewise as in Figs. 195, 196, the former being usual in thin tubes, the latter in thick tubes. Often gluts of triangular section, Fig. 197, A, are employed. Frequently, also, glut-iron having sections like Figs. 197, B and C, are used. These combine the vee with the flat form.

Iron is often used in preference to steel for gluts. It is difficult to make a good job of the welding of steel gluts, but, using iron, the job is relatively easy. The iron glut is heated to a temperature rather higher than the tube into which it is to be welded. It is usual to commence the weld, not at the ends, but at about the centre of the tube, and then continue it towards each end; a length of from 5 in. to 7 in. only being done at a heat.

Two forge fires are required for welding up tubes; one for the tube itself, the other for the welding strip. In the case of the tube, a clear coke fire is first prepared of sufficient area to well cover the length of tube which has to be heated for welding. The tube is then laid down upon this with the seam downwards, and the blast put on. The portion to be welded does not touch the coke at all, but is placed over a hollow fire. The smith judges of the heat by looking into the tube from the end, and by feeling it from time to time with the poker. The tube is slung from the crane hook; but in addition, a cross-handle, Fig. 198, is attached to it, to enable it to be moved and turned about, and held firmly during the operation of welding. The cross-handle has a forked end which slips over and clips the end of the tube, so that the smith's mate has complete control over it, while the weight is entirely taken by the crane. The small notch in the fork is for the insertion of a wedge.

FIG. 197.

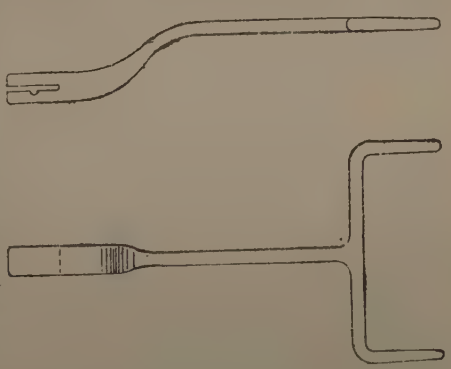


FIG. 198.

It is surprising, considering the length of the welds, and

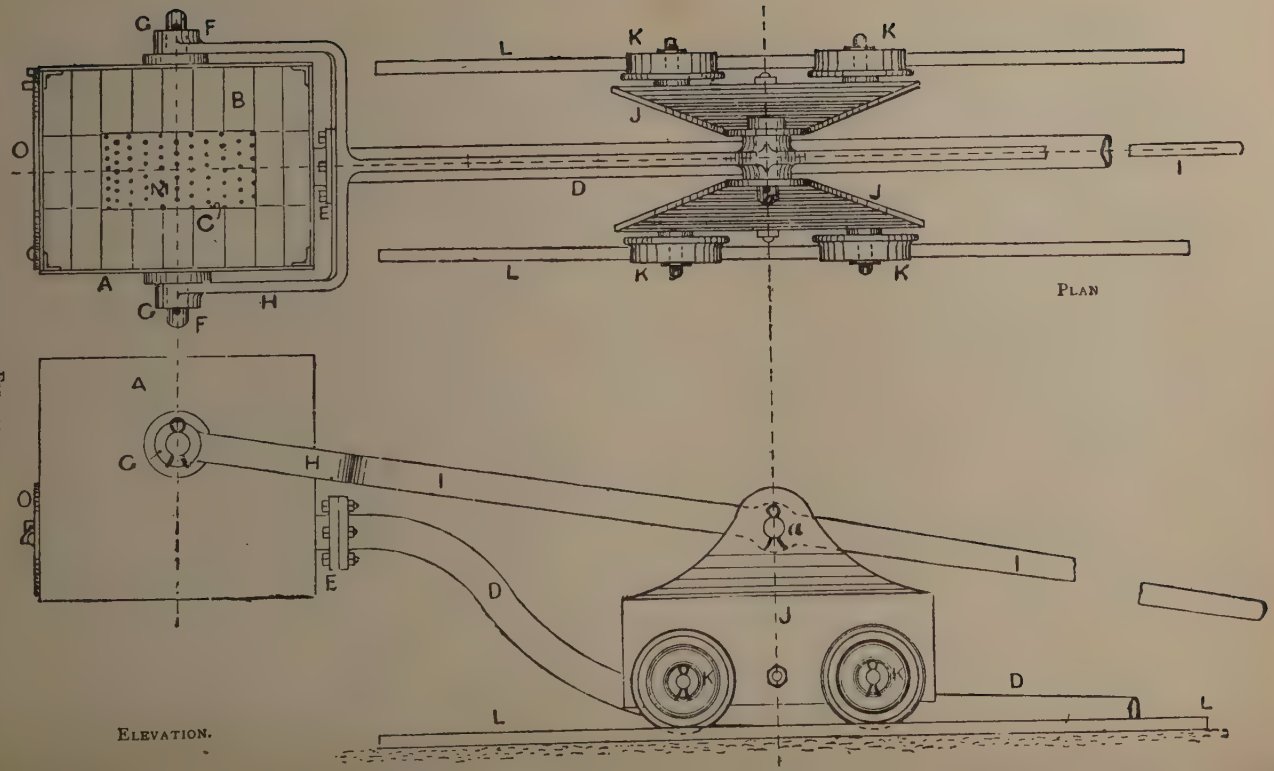


FIG. 199.

the high steam pressures to which tubes are subject, that these tubes so seldom leak. The operation appears extremely easy, and so it is to a skilled man; but, all the same, it is a specialised branch of work, so that many men skilled at other branches of the trade cannot earn their wages at tube-making. I do not mean to say that tubes are always welded up and finished soundly right off. A good deal depends on the iron or steel used, practically the steel now, for iron is used less and less for boilers. But, though steel tubes frequently show leaks, it is noteworthy, that the cracks occur less seldom in the actual weld than in localities adjacent thereto. When they crack, the cracks generally run longitudinally, close to the weld, being apparently caused by unequal tension due to differences of temperature in the heating and cooling of the metal. Such cracks are filled up by welding punchings or "burrs" of good iron into them, Bowling iron preferably, as many as are required. A wide crack can be detected while the tube is at a red heat by the crack appearing darker than the surrounding metal; but small cracks might not be visible at all. Then a rough and ready way of testing the tubes other than that of putting them under hydraulic pressure, is to let oil stand in them for awhile, when if there are cracks, the oil will soak through.

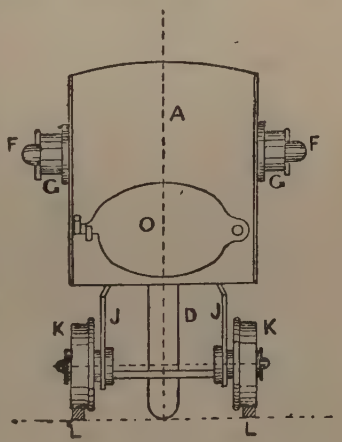


FIG. 200.
END VIEW.

Mandrels.—Tubes and cylinders are welded upon a mandrel, as shown in Figs. 192-195. These mandrels are usually of cast-iron variously formed, as seen. They may be flat on the lower face, as in Fig. 192, in which case the top face only is available for welding; or two or more faces may be rounded as in Fig. 194, the sweeps being different from one another to suit tubes of different sizes. They may be solid, as in Figs. 192-194; or hollow, like stout lengths of pipe, as in Fig. 195. The mandrels are clamped upon a bending block, or by any

other suitable means, and the small tubes will be well clear of the floor. But, when welding boiler-shells or fire-boxes, it is necessary to dig a hole in the ground in front of the bending block for the lower end of the shell to lie in.

Though it is easy to heat the small tubes over the forge fire, it becomes a troublesome job to heat boiler-shells in the same way. For such work a portable furnace should be employed.

Portable Furnace.—Figs. 199-201 illustrate such a portable furnace for heating the joints of boiler-shells and flues for welding. It is so constructed as to run on rails, and can be thrust into any required position within the shell, and can be elevated and lowered, standing parallel with the shell in any position. Its details are as follows :—

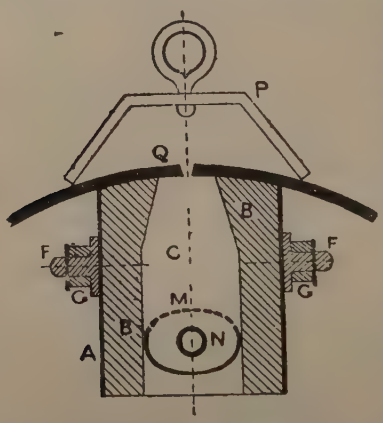


FIG. 201.—CROSS SECTION.

The furnace A is built up of thin plate and light angle, lined with bricks B. The top is curved to suit the average curvature of the shells. Coke is thrust in the interior space C, but the bricks become so highly heated that they are as effective in heating the plate as the coke. Blast is supplied to the latter from the shop-blower through a flexible hose D, attached to a pipe and nozzle E, screwed or bolted to the front end of A. The hose being flexible, and of sufficient length, adjusts itself to the movements of the furnace. Instead of a hose-pipe, telescopic pipes of wrought-iron having sufficient length of slide can be used. The furnace is swung upon the trunnions F, pivoting in the bosses G in the ends of the fork H, in which

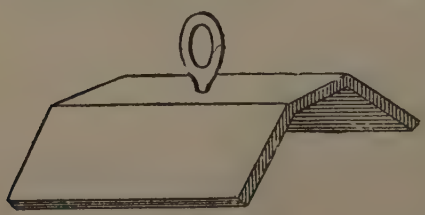


FIG. 202.

the lever I terminates, so that whatever its height, its top face is always parallel. It is elevated and lowered by the lever I which embraces the furnace by its forked end. The lever is pivoted upon the carriage J, running on the wheels K, on square bar L, or on the edges of small angle, laid parallel. The carriage is made of $\frac{1}{4}$ in. or $\frac{3}{8}$ in. plate suitably bent. The lever is pivoted upon a pin, *a*, passing through the sides of the carriage. The hinder end of the lever, shown broken in the figure, is longer than the other end, and may, if necessary, be weighted to help to counterbalance the weight of the furnace, which is, however, made of very light scantlings. Several holes may be drilled in the lever if desired, so that the distance between the carriage and the furnace can be varied to suit different lengths of shell. The interior of the furnace A is bevelled narrower towards the top, to cause the heat to converge only upon the weld and its immediate vicinity. The coke fire is made upon the elliptical iron shell M. This is pierced with holes over the top to permit the blast to pass from the interior pipe N, a continuation of the outer one D, to the fuel above. The ashes that fall through the holes into the elliptical shell are cleared out through the end door O, furnished with a latch. To confine the heat upon the weld a hood of iron, Fig. 202 and Fig. 201, P, is used. In Fig. 201 the boiler-shell Q is seen lying upon the furnace covered with the hood P.

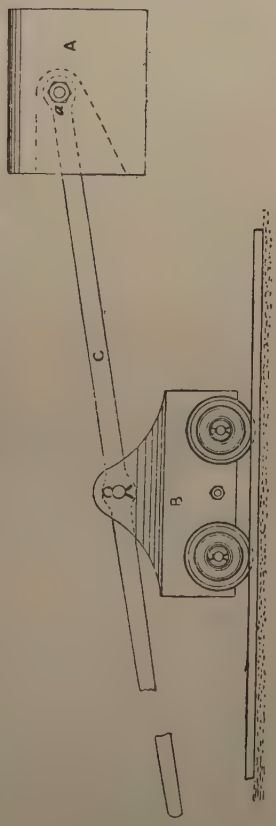
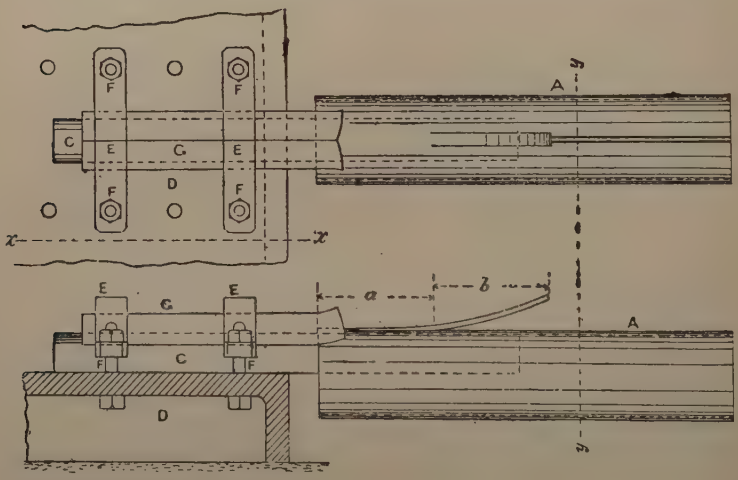


FIG. 203.

Portable Anvil.—As soon as the length of weld is heated sufficiently, the furnace is run back sharp along the rails L, and the portable anvil, Fig. 203, similarly mounted, is run

under into the spot just vacated by the furnace, and the joint hammered. I need not draw plan nor end-views of this. The anvil is smaller in length and width than the furnace, the drawings representing correct proportions. The carriage B is a duplicate in all respects of the carriage J in Fig. 199. The anvil A is of cast-iron, and instead of being embraced with a



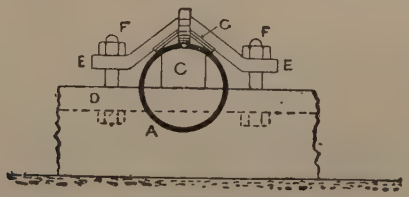
SECTION x—x.

FIG. 204.

forked end like the furnace, the bossed end of the lever C enters into a recess of about a couple of inches wide cast in the block. This recess is shown dotted in A, and *a* is the bolt upon which the anvil pivots. The rails are laid at the opposite ends of the shell, so that as the furnace is run out from one end, the anvil is run in from the other without delay. In some shops, instead of using a portable anvil, a mandrel is fixed under a light steam hammer, and when the furnace is run back from under the joint of the flue the weld is made upon the mandrel by the hammer.

Rig-up for Tubes.—A rig-up adopted in making the glut welds in small tubes is shown in Figs. 204, 205. Here A is the tube, partly welded, that is, the length *a* has been done,

and *b* is the length of glut strip standing beyond, ready to be cut off before the next length of welding can be done. The method of fixing is as follows:—C is the mandrel over which the tube A is slid for welding. It is clamped down upon the bending block D with the clips E and bolts F; but between the clips and the tube there is a piece of obtuse angle G, the function of which is the confinement and steadying of one end of the tube under the hammer-blows necessary for welding, the front end



SECTION *y—y*.

FIG. 205.

of the angle being slightly turned up for this purpose. This arrangement permits of the instantaneous confinement of the tube on the moment of its removal from the fire at the welding heat, when any delay occasioned by the screwing down of bolts would cause the heat to be lost.

CHAPTER X.

FLANGING.

Difference between Bending and Flanging.—Flanging in General.—Setting Down. — Flanging Flat Rectangular Plates. — Rigs-up. — Flanging Circular Plates.—Rigs-up.—Checking Accuracy of Flanges.—Flanging Tubes.—Rigs-up.—Checking Flanges.—Setting Out Fire-box Shell.—Adamson Seams.—Flanging Machines.

Difference between Bending and Flanging.—In some respects the operation of flanging is akin to bending, but the broad difference between the two operations consists in this: that bending is mostly done to long, relatively easy curves, with or without cutting or welding of certain portions, as already explained at length; while flanging is done to very quick curves, without any assistance derived from cutting and welding. The work is extremely difficult in many cases, because of the very minute radii to which the plates have to be bent, treatment which inferior plates will not endure without cracking.

Flanging in General.—The difficulty of flanging may be inferred from the list of cold forge tests given on p. 48. It is necessary when ordering material that has to be flanged, to state, except in the case of the highest brands, that it is wanted for flanging. Further, it is desirable in all cases where practicable, to flange *with* the grain, and not across it. The reason of this will be obvious on reference to the list on p. 48 just now alluded to. In many instances this is impracticable, as for example in the case of a circular plate, where two opposite portions must needs be flanged across the grain. Moreover, in difficult work, mild steel will always stand flanging better than iron, the products of the Yorkshire houses excepted. With these prefatory remarks, I will proceed to give some practical examples.

Setting Down.—But first I wish to describe a class of operations, the treatment of which, though not strictly coming under the head of Flanging, are more nearly related thereto than to any of the other operations which I have described, and I will therefore note them in this connection. I allude to the setting down of tees and angles when used as flanges

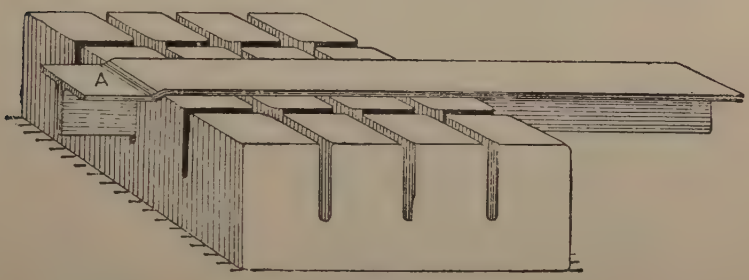


FIG. 206.

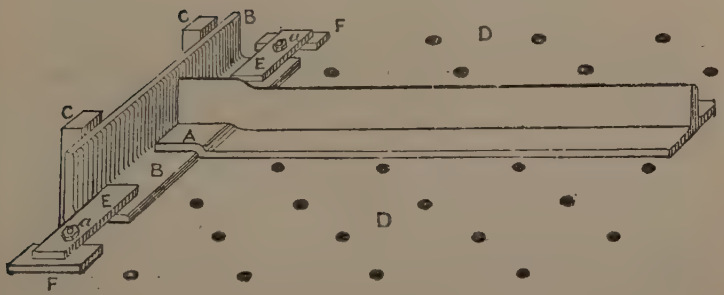


FIG. 207.

and stiffeners. This is a very common operation, the reason of which we shall see when we come to the various methods of jointing adopted by platers and boiler-makers. It is done whenever a flange, rib, or stiffener of angle or tee, has to be fitted over plate and angle, or tee, without being raised up on a fish or joint-plate. The details of the operation are shown in Figs. 206 and 207.

The end of the angle or tee which has to be set down is first heated in a bricked-up fire, like those shown in pp. 153, 156.

When at a full red heat, it is taken out and laid over the block, Fig. 206, the web of the tee lying perpendicularly in one of the grooves of the block, and the flange resting upon its top face. The end A of the tee is then roughly set down with a narrow fullering tool, struck with the sledge. Necessarily the surface thus set down is very irregular. To finish the set-down portion the tee is removed to a levelling block, upon which a piece

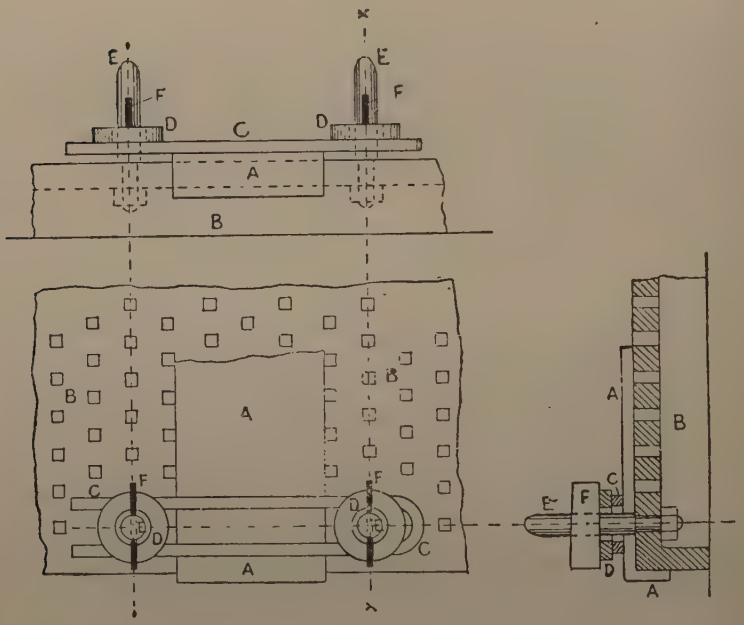


FIG. 208.

of angle of the same section as that over which the set-down end of the tee has to fit is bolted, and by means of hammer and flatter the end of the tee is made to fit neatly and accurately over the angle. This is shown in Fig. 207. A is the end of the tee being set down, B is the angle over which it is being fitted, C C are two blocks fitting into holes in the levelling block D, to prevent the angle B from striking away under the

force of the hammer-blows dealt on A, and E E are pieces of plate gripped by the bolts *a a* upon the angle B, F F being thickness pieces upon which the opposite ends of E E rest.

It often happens that these stiffening ribs or flanges have to stand at some angle other than a right angle. Then to ensure accuracy, and also uniformity, where quantities are concerned, a templet of iron has its edge cut to the angle required, and is bolted down upon the levelling block. One edge abuts against the edge of the angle B, and the other is the edge against which the edge of the tee is laid while the end is being set down. Instead of a plate, two or three pins may be used, if suitable holes for their insertion can be found in the levelling block; but the plate is safer.

Flanging Flat Rectangular Plates.—Coming to flanging proper, the simplest case which can occur is that of flat rectangular plates. These are bent over the edges of the levelling blocks, or over the edges of blocks specially made for the purpose. Thus, Fig. 208 shows a piece of rectangular plate A, being flanged over the edge of the levelling block B. After the end of the plate has been heated in the reverberatory furnace, it is rapidly clamped down upon the block in the manner shown. C is a clip or binder made by doubling round a piece of wrought-iron bar of square section. This is laid upon the plate A, two washers D D laid upon it, encircling the cottar-pins E E, which are screwed into suitable holes in the levelling block B, and the cottars F F being driven in, bind the washers D D upon the clip C, and that upon the plate A. The latter, therefore, is held firmly, while the end of A is flanged rapidly against the vertical face of the levelling block. Plates of any size and thickness can be flanged by this method.

Rigs-up.—A useful piece of apparatus for the flanging of thin plates and sheets is shown in Fig. 209. It is bolted against the face of a levelling block A. The appliance consists of two jaws, C and D, of cast-iron. The lower jaw C, is bolted to the face of the levelling block A, with bolts E E, which grip the plates F F against C, the plates being kept parallel with thickness pieces G G. The jaw C is therefore readily secured, and quickly detachable from the levelling block A. Two bolts, H H, pass tightly through the bosses in C, and freely up into the bosses D, so that D can slide up and down upon the bolts H H. D is tightened with the wing-nuts J J, so that when a thin plate or sheet, K, is placed between C and D, it can be

instantly gripped fast with the nuts, and the end flanged upon the vertical face of C. Thin sheets, by the way, are usually

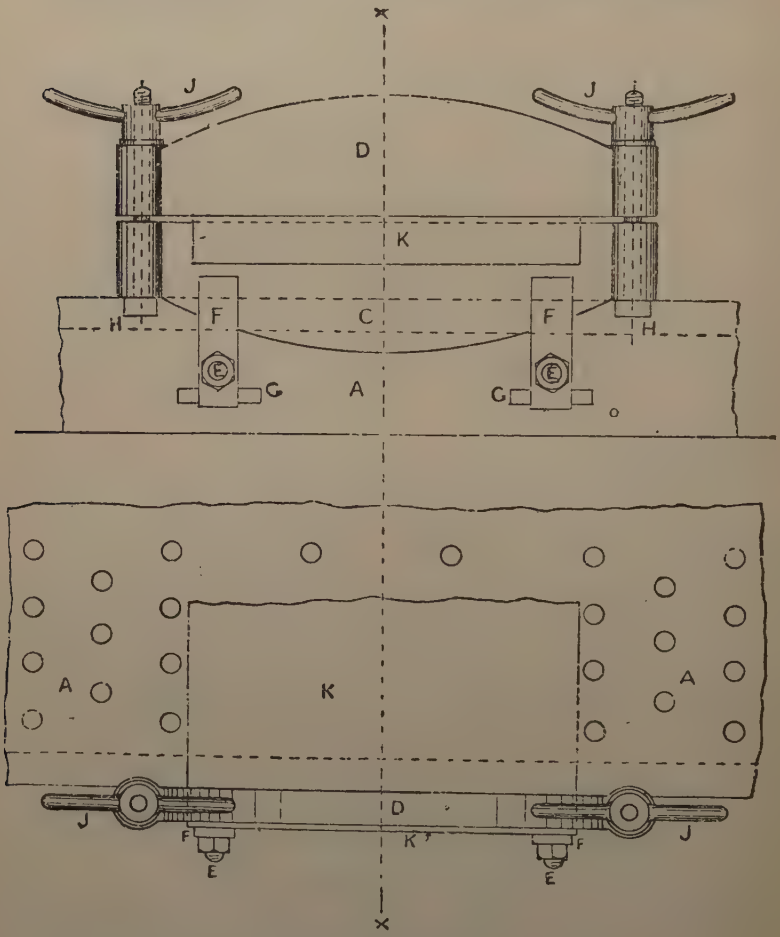


FIG. 209.—ELEVATION AND PLAN.

flanged cold. The flanging of rectangular plates of this character is sometimes done in the case of repetitive work in

special machines, in which a top slide is pulled down upon the edge to be flanged. The plate is laid horizontally upon a bottom fixed block forming a portion of the machine, and the slide squeezes the flange against its vertical face.

Flanging Circular Plates.—Rigs-up.—Segments of circles and complete circles are flanged upon blocks of various forms. The blocks may be either segments of circles or complete circles. In Fig. 210, A is a circular flanging block, bolted down by means of lugs upon the levelling block B, and C is a circular plate being flanged. A portion of the plate at C′ has been flanged, and the plate once removed, and another short section been done. The details of the work are as follows :—

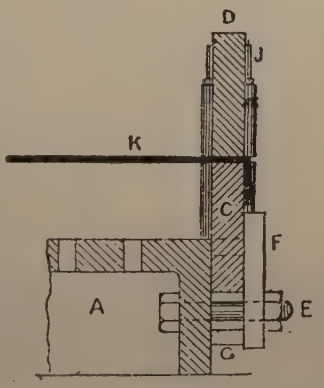


FIG. 209.—SECTION *x*—*x*.

The plate is first heated through a short section of its circumference in a bricked-up fire, Fig. 211, as described generally in p. 153. Bricks A A A are suitably arranged, and covered over with a piece of sheet-iron B, to confine the heat. Into the hollow space thus enclosed, the section of the plate C, which has to be flanged, is thrust, the plate being suspended in the slings D, dependent from the forge crane. No fuel comes in contact with the surfaces of the plate. When almost at a welding heat, it is removed, and rapidly clamped upon the ring A, in Fig. 210. The rig-up is the same in principle as that shown in Fig. 208. But in Fig. 210 the cottar-pins E E are square instead of circular, as in Fig. 208, and there are no washers between the pins and the doubled bar D. These are casual matters of varying detail.

The doubled bar D is laid upon the plate, embracing at the same time the cottar-pins E E, and the cottars F F being driven in, clamp it upon the plate C, and the flanging is done as rapidly as possible. Generally, and properly, wooden mallets are used, in preference to steel hammers, which are liable to bruise and injure the soft faces of the metal. Bruised faces in any plated work have a very unsightly appearance; many

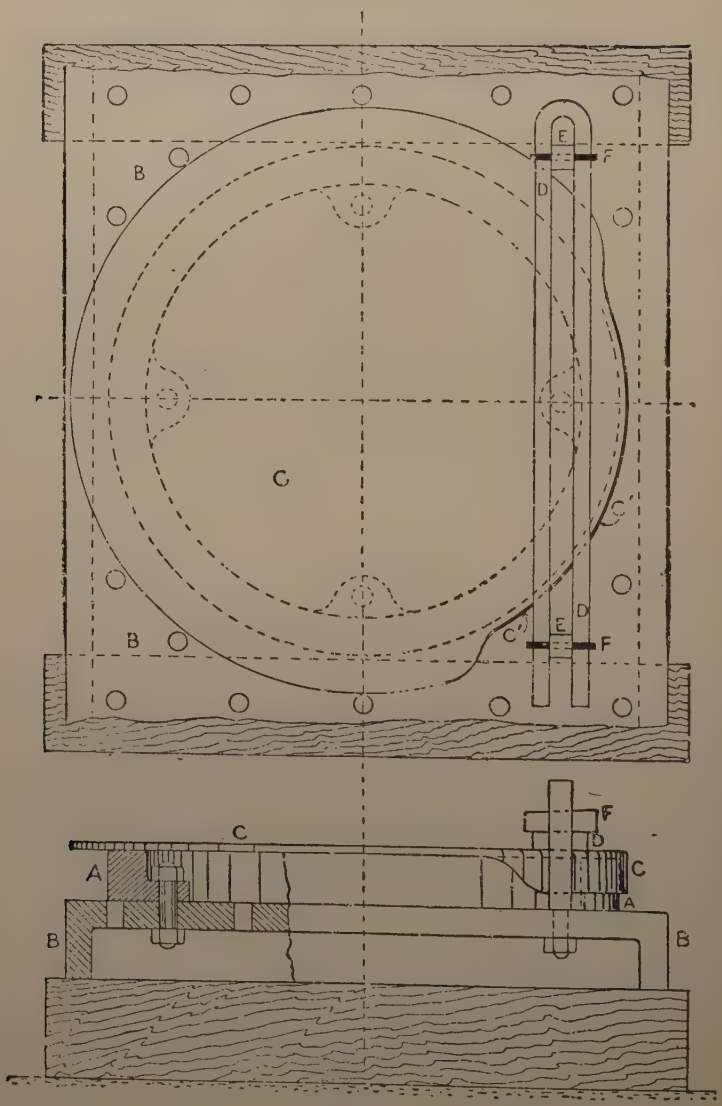


Fig. 210.

inspectors will not pass work so defaced. Hence, in many cases besides this, the use of wooden mallets is preferable to that of metal hammers.

Checking Accuracy of Flanges.—After the flanging is done the finish is imparted with flatters, partly done while the

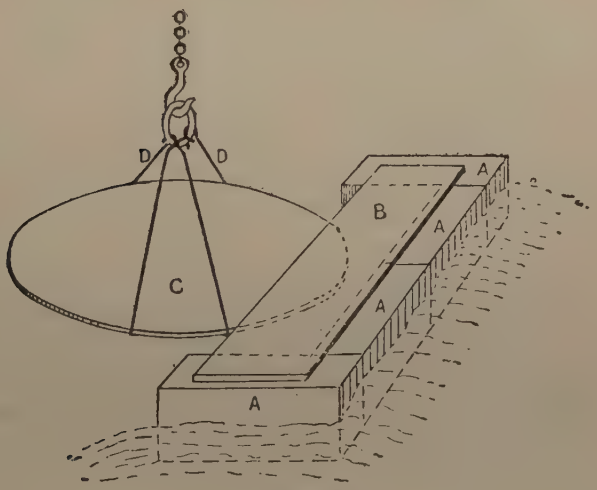


FIG. 211.

short sections are being bent, and partly after the circle is completed, when the whole of the flange is being tried and corrected. Fig. 212 shows how this trial and correction is done. A is the flanged plate, B is a templet block, and C is a try-square. The plate A being laid by its flanged edge upon the concave block—not necessarily cast to the same curvature as the flanged edge—and the stock of the square being laid upon the block, the accuracy or otherwise of the flanged edge is indicated by the coincidence or otherwise of the face of the plate and the edge of the blade. If the flange stands outward or inwards the plate is removed to the bending block, and corrected with hammer and flatter. But if the deviation from truth amounts to much, the whole plate is reheated in the reverberatory furnace, and laid upon its back upon a levelling

block, and the worst inequalities of the flange corrected while in that position. A piece of thin sheet-iron is laid on the flat surface of the plate while this correction is being done to check the more intense radiation of the heat, and permit of the workman performing his task. Afterwards minor corrections, if necessary, are made upon the edge of the bending block.

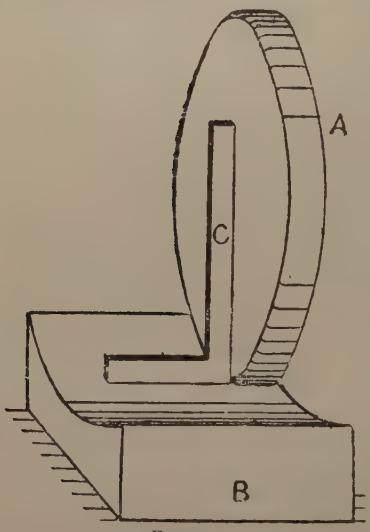


FIG. 212.

The method of checking shown in Fig. 212 is much more accurate than trying the flange with the blade of a square over the edges. When checked, as in the figure, slight inaccuracies are magnified by the amount of difference between the breadth of the flange and the length of the blade of the square. So that if the flange were out $\frac{1}{16}$ in. only, this would throw the plate off the square $\frac{1}{2}$ in. or $\frac{3}{4}$ in. perhaps, dependent on the length of the blade.

Fig. 213 shows an appliance used for flanging circles. Its utility chiefly consists in this, that it can be employed for circles of various diameters by simply changing the flanging block A, of which there will be several kept of various radii. The construction and methods of use of the appliance are as follows :—

A is the flanging block of cast-iron fastened with bolts B B to the cast-iron framing, C. This framing is bolted upon any convenient stand, usually upon the stand illustrated in Fig. 126, page 118, and in subsequent pages. It is bolted down to the stand through the cross-bar *a*; D is a pin movable in the slotted bar E, being tightened in any required position with the nut *b*. The slotted bar is secured to the main frame C by the turned down ends *c* and *d*, and the screw *e*. The pin D, being movable, is tightened at the exact radius of the plate

which has to be flanged, and, in the case of crown plates for boilers, a hole is drilled in the centre to fit over the pin, so that the radius r is made equal to the radius of the inner portion of the flange, to which radius also the block A is cut. The dotted

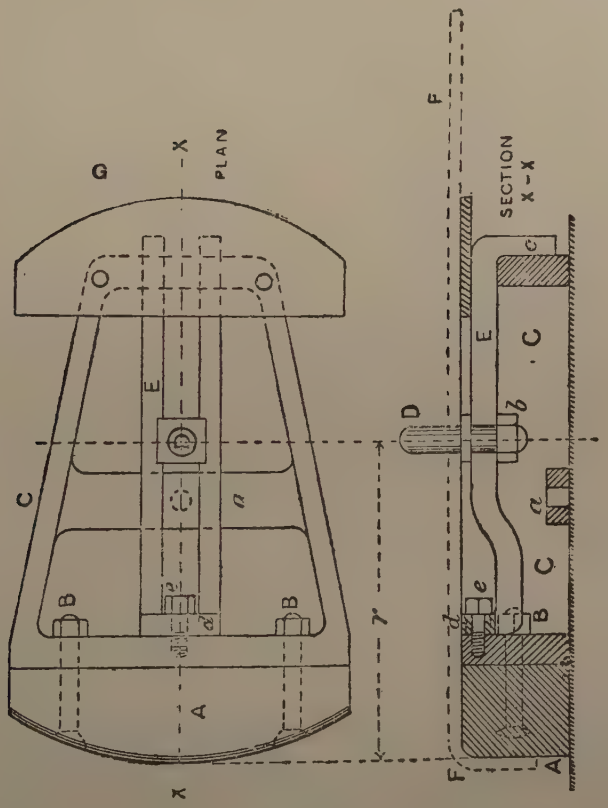


FIG. 213.

lines at F F in the figure represent the plate which is being flanged. The plate G is simply screwed on to the frame C to support the plate being flanged, at that end.

Note the radius of the curved edge of the block A, around

which the plate is bent. This radius should always be made as large as is consistent with the character of the job, because a large radius renders the work of flanging easier, and the flange is less likely to suffer fracture than when bent around a small radius.

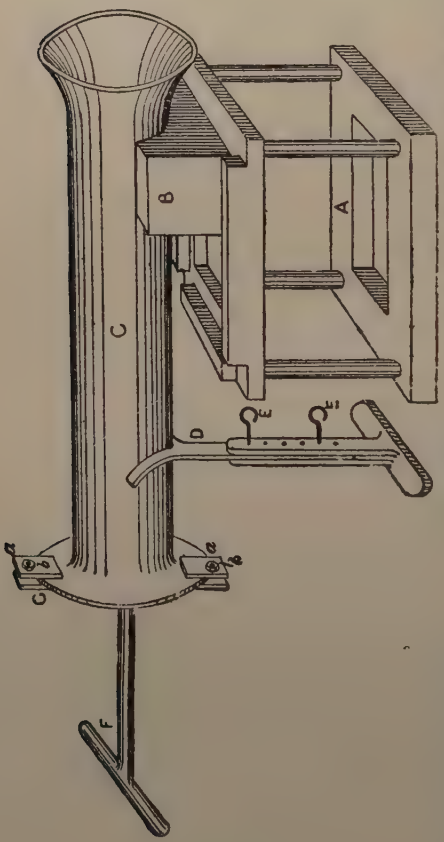


FIG. 214.

Flanging plates is more easy of accomplishment than flanging tubes. The flanges of the latter are very liable to crack in all but the very best qualities of iron and steel, under the severe treatment to which they are subjected. In any case, the work must be done very gradually, and at suitable heats. The following are the details of the process :—

Flanging Tubes — Rigs-up. — Fig. 214 shows the flanging of a tube at a certain stage—that is, when one end, that to the left, has been completely flanged, and the other, that to the right, has been about half done.

In the first place, after the tube has been rolled and welded by the method described and illustrated on page 182, it is clipped at one end with the holder shown in Fig. 198, page 177, and the end to be first flanged is heated in a clear coke fire.

The tube is then transferred to the stand for flanging. Upon the stand A, Fig. 214, a bedding block B, of cast-iron, made to the curvature of the tube, is laid, to form the support for the tube C. At the outer end the tube is sustained by the forked stand D, the height of which can be adjusted by means of the pins E entering into suitable holes in the stand. By means of the forked handle or porter shown in Fig. 198, page 177, the smith's mate is able to exercise pressure on the tube in opposition to the hammer-blows, and also to rotate the tube on the block B into all positions required during the progress of the work. So much for the preliminaries. Now for the actual flanging. This has to be done most carefully. In the first instance, the tube is, of course, quite parallel. In bending the ends round to right angles with the bore into the position seen at the left

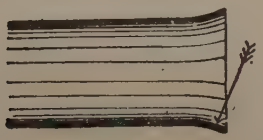


FIG. 215

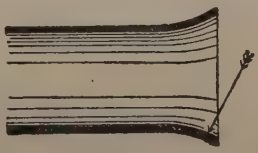


FIG. 216.

FIG. 217.

hand of Fig. 214, it is evident that the fibres must be immensely stretched and stressed. To flange tubes is therefore a crucial test of a man's ability. In any case also, the metal must be that suitable for flanging—highly fibrous and ductile. Two or three heats will have to be taken, and the mouth opened very gradually and regularly all the way round, the end being increasingly bell-mouthed at each slow rotation. Thus, in an early stage of the operation, the tube will be like Fig. 215, and the hammer-blows will be delivered into the mouth in the direction indicated by the arrow. Then the next stage will be that represented by Fig. 216, and the direction of the hammer-blows will be somewhat more inclined. At the next rotation the opening will appear as in Fig. 214—right-hand end—and so gradually the bell-mouthed end will be thrown back into a flanged end possessing a curvature adapted

to that of the boiler into which the tube has to fit ; the finished tube flanged at both ends being like Fig. 217.

When a considerable number of cross tubes are required, of the same size, the operation of flanging is much assisted by means of a hollow pair of hinged blocks having their faces rounded to the same curvature as the back of the flange. The flanging of the tube is done by hand as already described, until the flange is brought nearly into shape. But at that stage the body of the tube near the end is laid in the hollow portions of the hinged blocks and the flange hammered neatly to exact curvature against the curved faces of the blocks.

Ordinary hammers are not suitable for flanging these tubes. Wooden mallets, like that illustrated in Fig. 35, page 15, are used, and also the round-faced hammer shown in Fig. 218. These do not bruise the flanges as common hammers would do.

When one flange has been done, it is even more difficult to do the other, because the correct length of the tube over all

Fig. 218.

has to be ensured, as well as the flanging. Where large numbers of these tubes are done, there is less trouble ; but when only done occasionally there is rather more chance of getting them a little long or short, and once flanged, scarcely any correction can be made in the way of lengthening or shortening.

Before proceeding to turn the second flange, the one already made is clamped in a cross handle, through which the mate operates the tube. This cross handle is partly seen to the left of Fig. 214, and more clearly in Fig. 219. It consists of a handle, F, riveted to a piece of plate, G, long enough to extend a little way beyond the diameter of the flange. This plate abuts against the flange, and is clamped thereon, two small pieces of plate, *a*, *a*, being placed at the back of the flange to receive the tightening bolts *b*, *b*.

Another way to hold the flange is to drill a couple of holes in the flange corresponding in position with two of the intended rivet-holes, and pass a couple of bolts through the plate G into these holes and screw them up.

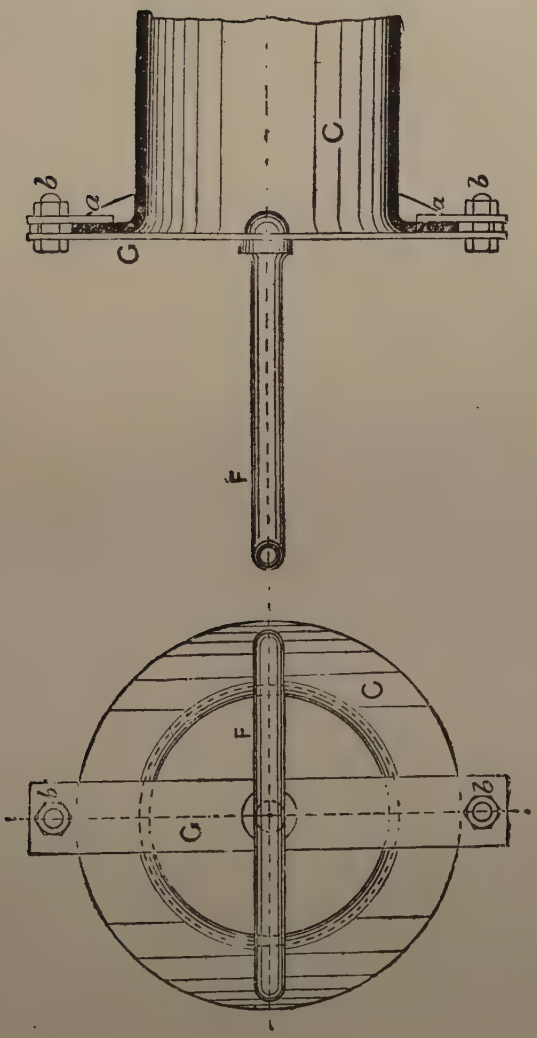


Fig. 219.

The flanging of the other end is then done in a similar manner to the first. Fig. 214 shows the tube at this stage when about half of the second flanging is done.

Checking Flanges.—The length of the tube is checked when the flanging nears completion by means of a rod, Fig. 217, A, turned down at one end to abut against the face of the finished flange, and marked near the other end to the correct length of the finished tube. The flanges are set to the proper curves with hammer and flatter, and checked by templet.

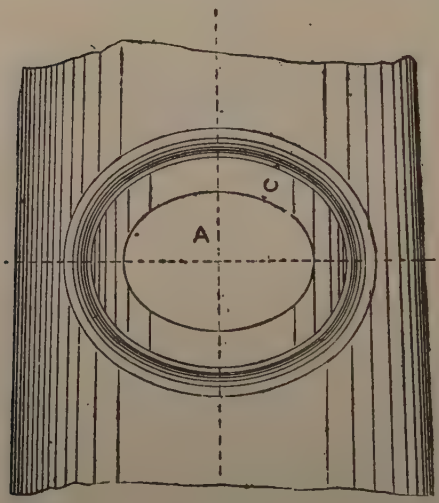


FIG. 220.

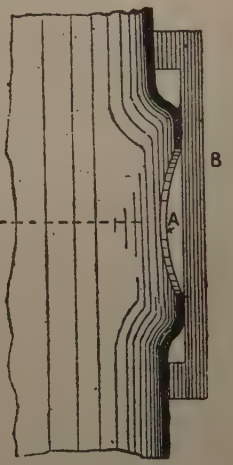


Fig. 221.

Setting Out Fire-Box Shell.—The operation illustrated in Fig. 220, though not an example of flanging, is allied thereto. It represents the setting out of a fire-box shell to meet the fire-hole ring. This is done after the shell is riveted or welded up, and after the elliptical hole A is cut out. The setting out is done at a red heat, either while the shell rests upon the forge, or upon a block like that shown in Fig. 121, p. 112. If done upon a block, the latter becomes a die and templet, ensuring the accuracy of the dished portion which has to be set out. The distance by which this part stands out from the shell is an

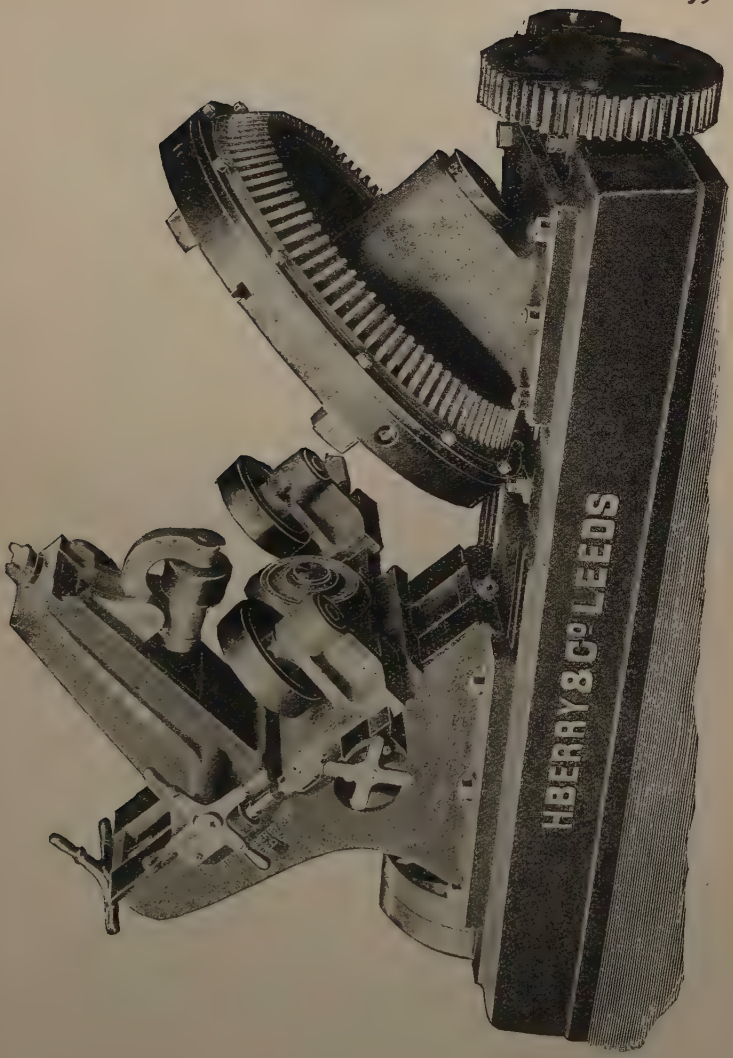


FIG. 222.

important measurement, and is checked round with a templet like B, Fig. 221, shouldered to rest upon the shell and upon the set-out part. In order to do this, the shell has to be turned round with the dished part uppermost. The smith judges of the accuracy of elliptical form viewed in plan chiefly with the eye, but measurement can be taken either with rule or templet of the width C, against which the ring is riveted. A good deal of correction has to be done before the correct height and true curve are obtained. An alternative method is to lay the fire-hole ring over the portion set out, and try a templet over the face of the ring and down on the shell. Then the templet or gauge will be parallel, instead of tapered, like that shown in the figure. The ring also becomes a test of the correct curvature, or otherwise, of the set-out portion of the shell.

Adamson Seams.—The flanging of the Adamson seams is seldom done by hand, as all boiler-makers of repute have put down machines to do this work, being so much superior to, and cheaper than hand work.

Flanging Machines.—Fig. 222 illustrates a boiler flue flanging machine. The construction includes a four-jaw chuck, like that of a lathe, placed at an angle, and rotated by pulleys and gearing; also a set of rollers on a slide opposite to the chuck. Three of these are on a lower saddle, the centre one supporting the flue immediately beneath, and the other two, adjustable laterally, steadying it at points on the circumference. An upper, or turning roller pivoted in a slide capable of being moved up and down forms the flange as the flue is rotated, the under bevel roller sustaining the flange.

In the very large shops, doing repetitive work chiefly, hand flanging, except in the case of occasional jobs, has almost become a thing of the past. Standard repetitive work is mostly done in flanging machines. Of these there are several types. In the machine just illustrated, the flanges of boiler flues are turned outwards in detail, not in dies, but by means of rollers. But the flanging of boiler ends is done between dies, male and female, attached to the top and bottom rams, and tables of the machines. They are alike in their mode of operation, which is that of the application of hydraulic power. In these machines the flanging is done by a single squeeze of the dies upon the plate, and special pairs of dies have to be cast for each distinct size of flanged end.

Fig. 223 illustrates a strong hydraulic flanging and forging

press manufactured by Messrs Henry Berry & Co. Ltd., of Leeds. In this the table moves upward to do the work. The base and the crosshead are united with stout pillars or columns, the height of the head or crosshead being adjustable to the extent of several inches. The table or platen of the press slides up

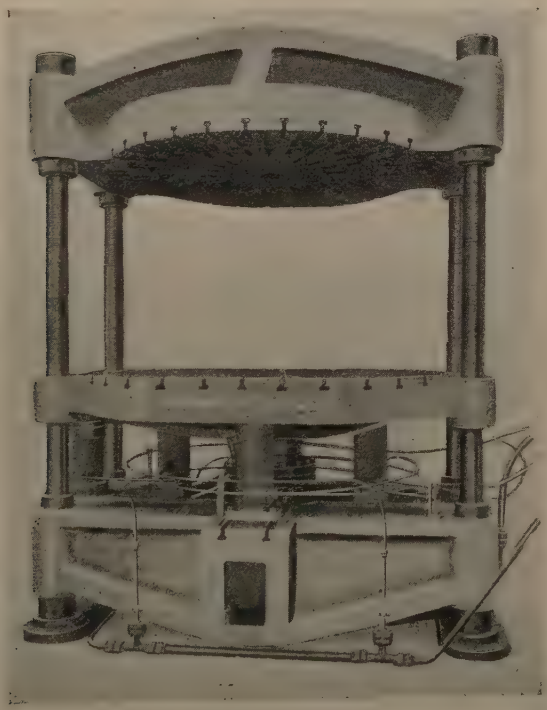


Fig. 223.

and down the pillars, being operated by the rams seen beneath. The dies are carried by the table beneath, and the crosshead above, by means of suitable bolts with tee heads, sliding in the slots cast in the table and crosshead.

The power of the machine shown is 300 tons, and it has a

width of 10 ft. 6 in. between the columns. The diameters and strokes of rams vary in differently-sized machines, as shown in the accompanying table.

Will admit Plates.		Diam. of Ram.	Stroke of Ram.
Ft.	In.	In.	In.
7	0	14	28
8	6	16	30
9	0	17	36
10	6	20	40
11	6	24	50

For further illustrations of flanging machines, *see* p. 313.

CHAPTER XI.

PUNCHING.

Marking Holes for Punching—Whitening Plates.—Marking Centre Lines and Circles.—Centre Popping.—Machines.—Operation of Plates under the Punch.—Supporting Beams.—Sling Chains and Bars.—Stands.—Punches and Dies, or Bolsters.—Proportions, and Taper of.—Necessity of keeping Cutting Edges keen.

Marking Holes for Punching—Whitening Plates.—Holes which have to be punched are marked out in various ways; as, directly by means of dividers and compasses, from templets, and with tubes through other holes, as follows:—

Before a plate is marked out with dividers it is usually whitened with a thin solution of common whiting in water. Sometimes it is chalked over, but the whitening solution is much better, because it does not brush off. On the whitened surface, when dry, the centre lines of the rivet holes are scribed, usually with a compass scriber (*see* Fig. 50, p. 19) working from the edges of the plate if the edges have been planed, or by the edge of a straight-edge if the edges are too rough to allow of the scriber being moved along them. In the event of the plate not having been whitened, then a fine chalk line is stretched, and the chalk transferred therefrom to the black plate forms a very fine white line, perfectly straight and distinct.

Marking Centre Lines and Circles.—Holes are marked directly through templets, or through holes in adjoining plates, either with the punch, and in the manner shown in Fig. 48, p. 18, or by means of a piece of brass tube whitened on the end. The tube just fits the hole, and being thrust through it, down upon the plate underneath, and slightly rotated, it marks a white ring upon the latter, corresponding with the circle of the rivet hole.

Should centre lines be curved lengthwise, then they are either scribed from the edges of the plates, or marked from the

edge of a templet, or struck with a trammel, according to particular circumstances.

FIG. 224.

Holes for punching are rarely marked out otherwise than on flat plates, the holes being punched before plates are bent. In cases where holes are made after plates are bent, then they are drilled, and not punched.

Centre Popping.—The best way to mark rivet holes, and the method generally adopted, is to centre pop the centres of the holes. This is either done with a common centre punch, as when marking holes directly, or with a punch like that shown in Fig. 48, p. 18. The centre pop then becomes a guide for the punching of the hole, a conical point on the punch entering into the popped hole in the plate.

When marking plates they are laid upon any convenient support, as two trestles of wood, so as to be at such a height that the marker-out need not have to stoop excessively.

There is not much to be said about the punching of the holes. The work is done at the machine, a punching-bear only being used in repairs, and in odd sections of work which would be inconvenient to bring to the machine. Two men, or sometimes three if the plates are large, are engaged in punching at the machine. I will first allude to the machines used, and then I will briefly describe the method of performing

the operation, with a few of the rough-and-ready appliances made use of.

Machines.—Punching machines are most often combined with shearing machines, as already noted and illustrated on pp. 70-73. But as noted there, it is better for heavy work to have distinct machines for each operation. In both classes of machines the motive power may be derived from an independent engine, or brought from line shafting to belt pulleys, or from water pressure. Punching machines usually operate in a vertical direction, but many are made to operate also in a horizontal direction, either as independent machines, or in combination with beam bending and angle shearing machines. Usually these machines are made to punch one hole only at a time. But many multiple punching machines are now made for bridge and girder work, capable of punching from 30 to 40 holes at one descent of the slide. Since a good many matters connected with the details of these machines call for remark, I will not digress here, but

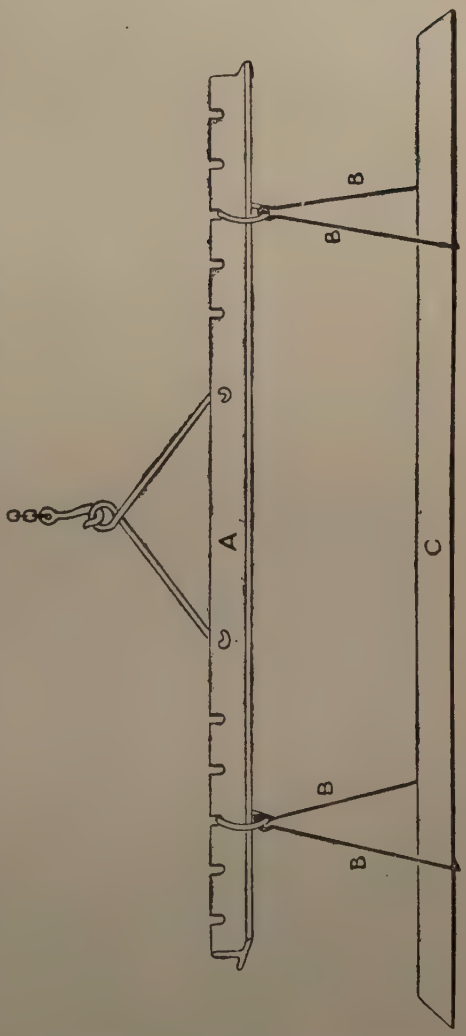


FIG. 225.

treat them somewhat at length in the chapter on machines p. 295.

Operation of Plates under the Punch.—In punching small pieces of plate the puncher requires no assistance at all, but simply manipulates the plate along, moving it by hand into the successive positions for punching the holes. In this, as in all punching, he sits on a low stool in front of the machine and steadies the work on his knees while moving it about with the hands. The hands are protected from the rough jagged edges of the plates with pieces of old nail-bags.

FIG. 226.

The vertical movement of the punch being very slow, usually gives a sufficient interval of time between the punching of one hole and the bringing the plate into correct position under the descending punch for the succeeding hole. But sometimes the man is not able, especially in large heavy plates, in the setting of which he is partly dependent on his helpers, to set the plate accurately quick enough. Then there is a throw-out, or knock-out, or stop movement attached to the punch, by which, though the punch still descends, it is pushed back in its socket directly the point touches the plate. This gives time for the attendant to complete the adjustment of the plate, on the completion of which the stop-gear is thrown back, and the punch descends effectively. But for this arrangement, many holes would be punched wrong.

In all except the smallest pieces of plate and bar, the assistance of a helper or helpers and of tackle is necessary. In plates and bars of moderate weight the assistance of helpers is sufficient. In heavy scantlings tackle as well is required. These helps, who are only unskilled labourers, acquire nevertheless a fair amount of dexterity in moving about the plates in unison with the puncher. As regards the tackle used, this is of a varied character, to suit varied work. The clips shown in Fig. 225 are employed mostly for broad plates. For bars, angles, and narrow plates the tackle shown in Fig. 224, and other arrangements of kindred type, are employed.

Supporting Beams.—Fig. 224 illustrates a method of supporting long heavy bars during punching. A is a beam dependent from the jib crane which serves the machine. Two sling-chains B B hang over pulleys attached with hooked loops to the ends of the beam. The bar C is supported in the bight of the chains. The workmen are therefore relieved from the entire weight of the bar, and have merely to slide it along under the punch. The same appliance is suitable for carrying angles. Fig. 225 shows an appliance suitable for supporting plates. A beam of tee iron A is sustained in the crane with a double eye bar. The top edge of the tee is notched at intervals to carry loose rings, from which the bars B depend, sustaining the plate C by means of their turned round ends. The supporting bars B, with their rings, are moved to the notches which happen to be most conveniently situated to suit the length of plate which is being punched.

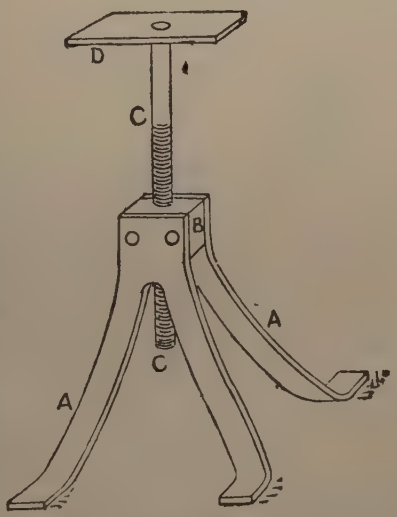


FIG. 227.

Sling Chains and Bars.—For supporting one end only of a bar or plate, as well as for supporting long work which is being heated in the forge fire, and manipulated upon the anvil, the form of sling shown in Fig. 226 is very serviceable. The S hook A is hitched in the jinny of the jib crane. B is a swivel loop hung therefrom with an adjustable swivel C, operated with a bar through the hole in its boss. D is the eye in which the swivel turns, and which is provided with a hook at its lower end, to which is hooked the fork E, carrying the loose pulley F, and sling chain G. The advantage of this lies in its adjustability for vertical height through the medium of the screw C.

Stands.—A low adjustable stand which is used for supporting the free ends of long pieces of work, as well as for

a multiplicity of purposes in connection with the forge, is shown in Fig. 227. It consists of two legs of flat iron A, A, suitably curved and spread, with feet, united with rivets to a block B, through which a thread is tapped to receive the screwed rod C, adjustable therefore for height. A flat piece of plate D is riveted to the top of C, and upon this the work rests.

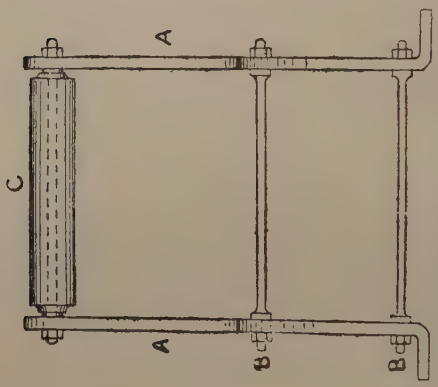


Fig. 228 shows another appliance, used, like the previous ones, not only for supporting work at the machines, but also at the anvil. It comprises two cheeks A, A, with stretchers or distance-bolts B, B, and a top roller C. The work runs freely on the roller. The means of adjustment in this case are the several holes *a*, drilled in the cheeks, and into which the long bolt which carries the roller C is inserted to suit the height of the work in hand.

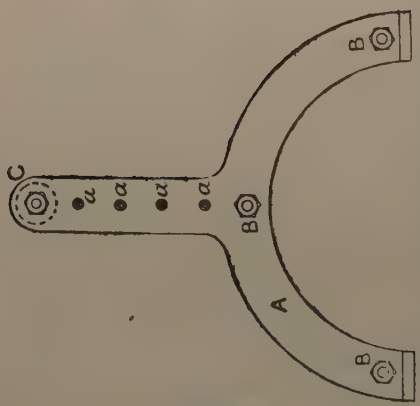


Fig. 228.

Punches and Dies, or Bolsters.—The character of the holes punched depends upon the sectional forms and dimensions of the punch and die. A punched hole is necessarily larger at bottom than at top—in other words, countersunk. The thicker the plate, the larger the amount of countersinking. There must

needs be a certain amount of this tapering downwards; but too much is injurious, because it tears out and opens ou the grain of the metal towards the bottom face of the plate. A die of too large diameter will produce too much countersinking. Hence the diameter of the die must bear a due proportion to the diameter of the punch used. So that for every punch of different size a separate suitable die must,

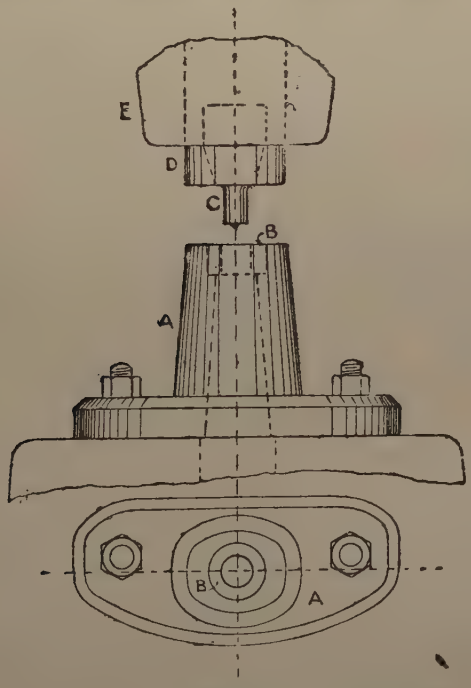


FIG. 229.

or, at least, ought to be employed. Yet clearance must be allowed between punch and die, else the burrs or punchings could not pass through freely. Also the die must be tapered downwards to allow free delivery downwards of the burrs. These matters determine the correct formation of punches and dies.

Fig. 229 shows a punch and die. A is an iron socket casting, which is bolted upon the lower portion of the framing of the machine; B is the actual die, of hardened steel; C is the punch, D its holder, attached to the movable arm E of the machine. The socket is formed of two portions, Fig. 230; D′ the main part, D a collar which encloses and confines the punch C. The knock-out lever, when thrown into gear, bears upon the top *d* of the socket. Fig. 231 shows the punch and die enlarged.

Proportions, and Taper of.—The tapers and proportions in Fig. 231 are correctly drawn, and are as follows:—In a $\frac{3}{4}$ in. punch, the punch will be that size at the point A, and will taper upwards about $\frac{1}{32}$ in. in diameter at B. The die will measure $\frac{7}{8}$ in. at the top C, giving $\frac{1}{8}$ in. clear between the punch and die. The die will taper downwards to the extent of about $\frac{1}{8}$ in. in its depth of $1\frac{1}{2}$ in. at D. That is, it will measure 1 in. in diameter at the bottom. It should not be larger in diameter, and its taper should not be greater; neither should it be less. The proportions between dies and punches of both smaller and larger sizes will be similarly maintained.

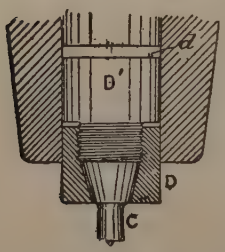


Fig. 230.

A method of obtaining the clearance between punches and dies is, to take a cone 2 in. diameter at the base, and 12 in. high, and set off on that the thickness of the plate. The thicker the plate, therefore, the greater the clearance. The following formula is also given for the clearance of punch and die:—

$$\text{Clearance} = D = d + 0.2t.$$

Where—

D = diameter of hole in die block.
d = diameter of cutting edge of punch.
t = thickness of plate in decimals of an inch.

Necessity of keeping Cutting Edges keen.—Punches and dies must be kept keen around the edges. The operation is akin to that of shearing, and it would obviously be impossible to shear a plate properly with blunt shears. Yet punches and dies are often used with blunted edges, and the

work is consequently stressed excessively. Not only should the edges of punches be keen, but their faces should not be in the least convex, as that impairs their cutting power. They must either be quite flat, or, better still, slightly concave. Some punches are made with flat faces only, without a central conical point; but the latter are much to be preferred by reason of their superior guiding capacity. Some punches also are made with faces slightly helical in form, by which it is supposed that their cutting action is rendered easier and more gradual, the edge cutting in detail, akin to the diagonal cutting practised in many hand and machine tools. But they are not nearly so much used as the common type shown in Fig. 231.

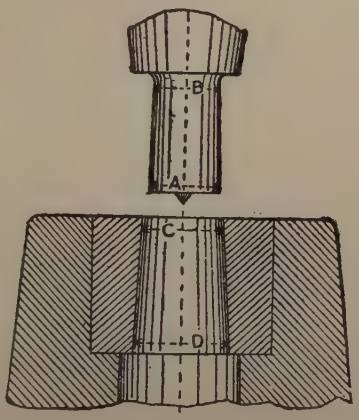


FIG. 231.

The thickness of plate which can be punched with a punch of a given diameter must not exceed the diameter of the punch. It is better if less, especially with inferior plate.

CHAPTER XII.

RIVETING.

Placing of Plates for Riveting.—Reamering Punched Holes.—Sets of Riveters—Division of the Work.—Holding-up Hammer.—Caulking.—Caulking Plates and Rivets.—Tanks.—Cutting out Rivets.—Iron, and Steel Rivets.—Countersunk Rivets.—Proportions of Rivets.—Machine and Hand Riveting Compared.—Hydraulic Riveting.—Pneumatic Riveting.—Rivet Furnace.—Description of Hydraulic Riveting Plant.

Placing of Plates for Riveting.—When plates are riveted together, the larger diameters of the holes are always placed outwards. Then the closing of the hot rivets fills up the enlarged portions. Therefore plates and bars must be so laid while being punched, that the larger diameters of the holes shall come outwards when the work is being put together, Fig. 232. In some cases this is not practicable, but it is a rule to be observed whenever convenient. If riveting is performed with the larger diameters of the holes facing each other (Fig. 233), the rivet does not fill up the enlarged portions so perfectly as when the larger diameters face outwards, as in Fig. 232. The plates are then liable

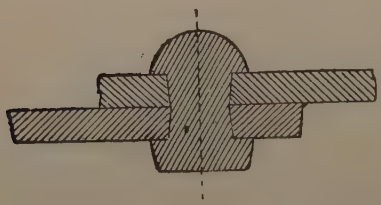


FIG. 232.

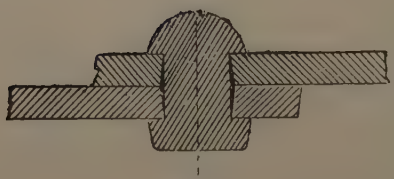


FIG. 233.

to slide over one another when subject to excessive stress (Fig. 234), and an initial tendency to shear off is imparted to the rivets.

The closeness of a rivet joint is sometimes illustrated by slotting pieces of plate through the centres of the rivets. If the work of riveting is well done, the joints between plates and rivets are seen to be so close that the metal is practically continuous, so that when the specimen is allowed to become rusted, an unpractised eye would not be able to detect the joints.

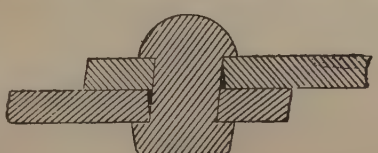


FIG. 234.

Reamering Punched Holes.—In ordinary girder work it is usual, unless otherwise specified, to insert the rivets in the punched holes. But in all the best work, and in all boiler work, the holes are reamered out. It is necessary to reamer out punched holes, because the punching stresses the fibres adjacent to the hole severely, and produces incipient cracks, which are apt to develop subsequent fractures. Reamering out the hole removes the stressed portion and the minute cracks, and opens out the hole to the adjacent sound, solid metal. Many engineers will not have anything to do with punched holes at all, even though reamered, but insist upon all holes being drilled through the solid plate. Doubtless they are on the safe side, because there is always some uncertainty present in regard to the care, or otherwise, with which the punching and reamering has been done. Punching is much cheaper than drilling. But for certain classes of repetitive work, special machines are designed, and used to a considerable extent. These are alluded to and illustrated in Chap. XVII., p. 307. But a hole punched properly in good ductile plate, and reamered out to the extent of $\frac{1}{8}$ in. in the diameter, or, say, $\frac{3}{16}$ in. in a large hole, is nearly as good as a drilled hole. But there is rough, violent work done, and contract specifications are evaded in boiler work, as in work of other kinds. The same thing occurs in shearing. The shorn edges are stressed and cracked by the violent detrusion to which they are subjected. Such edges are always planed subsequently for good work. So also when punching a series of contiguous holes in the operation of cutting man-holes, fire-holes, mud-holes, and similar curved portions, as

described on p. 79, the punch is always kept about $\frac{1}{8}$ in. away from the lines marked, and the punched edges cut away and finished subsequently with clipping chisel or other means.

Sets of Riveters—Division of the Work.—Riveting is performed by "sets" of men. A set comprises three men and a boy, and includes two riveters, one holder-up, and a rivet boy. The work is divided as follows :—The boy heats the rivet, and bringing it to the job inserts it in the rivet hole, the holder-up slips the dolly underneath the rivet head and exercises the

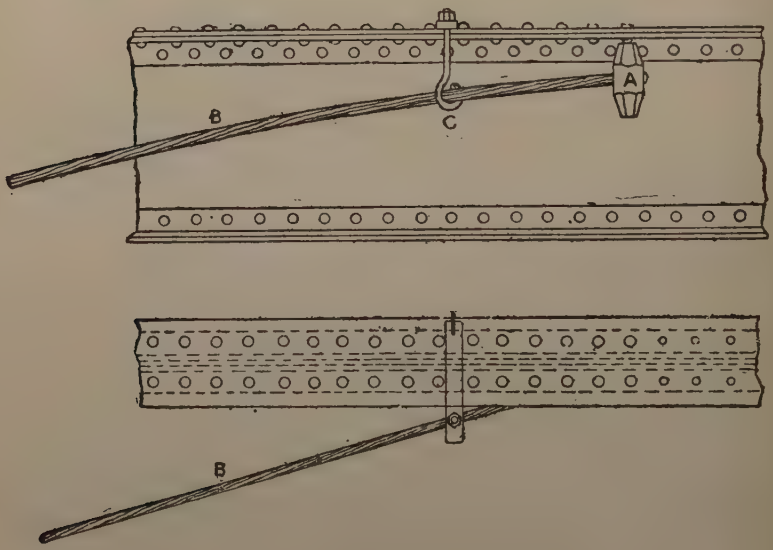


FIG. 235.

necessary pressure against it, and the two riveters close the tail with rapidity, delivering alternate blows. When closed, the finish is imparted with a snap held by one man, and struck with a sledge by the other.

Holding-up Hammer.—Holding-up dollies were shown in Figs. 56 and 57, p. 22 ; but these are chiefly used in contracted spaces where no more effective appliance can be rigged up. In girder work a rig-up like that shown in Fig. 235 is used. It consists of a heavy holding-up hammer A, on the end

of a long elastic handle B. The handle is slung in a loop C, suspended with a screw-bolt from any rivet hole conveniently situated, or from a strap clamped on the girder, or held in rivet holes as happens to be most convenient, and the leverage afforded by the long handle B allows the helper, by pressing down thereon, to exercise sufficient pressure on the holding-up hammer A, to resist the impact of the rivet blows. The loop C is moved from time to time into fresh positions as the work proceeds.

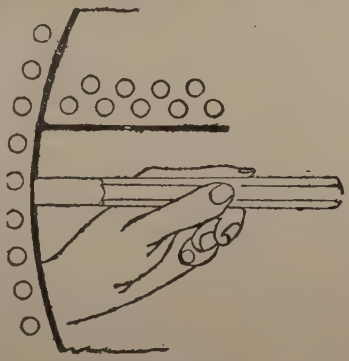


FIG. 236.

Caulking.—Caulking in boiler work is not done by the insertion of some substance impermeable to water, but by the burring-up of the edges of the plates. All riveted boiler work, without exception, has to be caulked, for although the plates are brought as close together as practicable, yet their surfaces, being more or less rough, leave minute spaces through which liquid will ooze. Even rivets, though their contact is closer than that of plates, will often leak.

Caulking Plates and Rivets.—Caulking consists of throwing-up or burring-up the edges of the plates or rivets, as the case may be, with one of the caulking-tools shown in Figs. 36–39, p. 16. The tool is generally held in the left hand in the manner shown in Fig. 236, and struck with the hand hammer, held in the right. It will be noticed that the face of the tool, p. 16, is bevelled. It is generally used with the acute angle first facing outwards, and then inwards. That is, with the acute angle presented outwardly, the edge of the plate is first caulked, as shown in Fig. 233. Then the tool is reversed, and the acute angle presented inwards, leaving the caulked edge finished, as in Figs. 232 and 237.

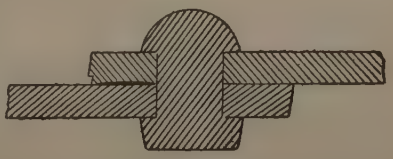


FIG. 237.

When moving the tool along longitudinally, it should not be moved through its whole width at once, but only over a portion of it—say, two-thirds. If moved along its whole width, the chances are that there will be minute portions of the edges left uncaulked, and these will subsequently leak. From one to two blows is sufficient to give at each spot. The roughening up of the face of the tool prevents it from slipping, and a caulked edge shows the corresponding cross hatchings.

Bad caulking is a fruitful source of after-grooving in boilers. If the edge of the tool is allowed to cut into the surface of the plate, it will form an incipient groove, more especially in parts subject to alternate expansion and contraction. The salts in the water will eat into the exposed metal, and corrode the plate away. The caulking tool should therefore only be operated upon the edge of a plate—not upon the surface of the adjoining plate—and it must never therefore be held at too high an angle.

The thickness of a caulking tool must bear a due proportion to the thickness of the plate being caulked. Too thin a tool will wedge open the plate, as in Fig. 237, leaving a space where corrosion will be set up. So also will a broad tool, if the plates are not a close fit. Broad caulking, or "fullering," however, is often adopted when plates are not close, because the broad tool does not wedge them open, but just closes the edges. Still, as the interior faces are still left open, it is obvious that, unless plates are close in the first place, no caulking will close them beyond the immediate edges. The open space will still be left in the interior, for future corrosion to operate secretly in. A tool having a $\frac{3}{16}$ in. face is generally suitable for plates from $\frac{3}{8}$ in. to $\frac{3}{4}$ in.; over that, broader tools are used.

Caulking is much facilitated by the planing of the edges of the plates.

A practice sometimes adopted is to use sal ammoniac to close up bad joints. This is only a temporary and a bad practice.

It is usual to caulk the rivets in fire-boxes previous to the insertion of the fire-boxes in their shells; but the shell rivets are seldom caulked, except such as leak after testing. The reason why the fire-box rivets are caulked is, that if they were to leak after testing many of them could not be caulked, except by removal of the fire-box from the outer shell. When a boiler is tested, if leakage occurs round the rivets, they are marked

with chalk, and afterwards caulked around the snapped portions.

It is the practice, also, to caulk round the inside of fire-hole doors and around foundation rings, the caulking being done along the joints of the plates with the rings.

Tanks.—Tanks, as a rule, are not caulked. The plates are so thin that it is difficult to make a close joint by caulking. It is easier and cheaper to insert something in the joints to render the tanks water-tight. A thick application of red lead paste may often be sufficient, but it is usual to insert besides a layer of brown paper, or of wire gauze, or of thin sheet tin, or iron. Both surfaces of the insertion material are smeared with red lead, and when riveted up, the joints are water-tight without caulking.

Cutting out Rivets.—Rivets have to be got out of their holes whenever repairs necessitate the putting in of new pieces of plate, or when in putting in rivets the snapped portion becomes badly cracked. They are removed by first cutting off the tail with a rivet sett (Fig. 41, p. 17), one man holding the sett while his mate strikes it several blows with a sledge, by which the tail is shorn off. Then the point of a tapered punch (Fig. 42 on the same page) is held upon the shorn end of the rivet, and a few hammer-blows delivered on the head of the punch drives out the rivet. In this way rivets are removed very expeditiously, except when men have to work in confined situations, in which some very awkward jobs occur.

Iron, and Steel Rivets.—Iron rivets have been generally preferred to steel, notwithstanding the higher ductility of the latter. Steel rivets are very apt to fracture short off under the heads when subjected to sudden stress, whereas iron rivets will yield. In boiler shells, B B rivets are used; in fire-boxes, Lowmoor or Farnley rivets ought to be used. But these being costly, B B rivets are commonly employed throughout. Mild steel of suitable quality is now, however, generally used.

Countersunk Rivets.—Countersunk riveting, though used largely in certain parts of girder work, is not much employed for steam boilers. Such rivets are ill adapted to sustain direct tensile stress, because of the shallowness of the countersunk portion. Countersunk rivets cannot, of course, be snapped. The tails are beat over by two men using small-faced hammers, until the countersunk holes are quite filled up. There is then usually a very little material standing up above

the face of the work, and this is cut off with a hot set. Finally, the rivet may be finished and smoothed with a few taps of the hand hammer.

Proportions of Rivets.—The height of a finished snap-head should be about five-eighths or three-fourths the diameter of the shank. The allowance in length necessary for this is about one and a quarter times the diameter. In machine riveting a little more, or from $\frac{1}{8}$ in. to $\frac{1}{4}$ in. extra, is allowed. The extra length allowed for countersunk rivets is equal to the diameter.

Machine and Hand Riveting Compared.—Hydraulic and pneumatic riveting have largely dispensed with hand riveting in all but the little struggling shops, in outdoor work, and in the hulls of ships. The difference in cost of putting in rivets by hand and by machine is so great that a hydraulic or pneumatic plant soon pays for itself, and yields a handsome profit. Thus, the average price for putting in $\frac{3}{4}$ in. rivets by hand is usually about 7s. 6d. per hundred; the price for putting them in by machine is from 1s. 6d. to 2s., dependent on their position. More than this, the work is done better. In a machine, a steady pressure of, say, 25 tons is exerted at one instant upon the rivet, closing it at once. If done by hand, there are perhaps a dozen or fifteen blows delivered before the tail is snapped; and by the time it is being snapped the rivet is getting cold—approaching that black or blue heat which is so dangerous; so that while a considerable proportion of hand-closed rivets will be found cracked if inspected critically, there will be few or none found so among machine-closed rivets, unless, indeed, the men spend too much time in setting the machine previous to closing, and so allow the rivet to become too cold, which practised men would not do. With machine riveting faulty rivets are rare; in fact, five or six rivets can often be seen in succession all still at a red heat.

Hydraulic Riveting.—Riveting by hydraulic pressure is extensively practised, being better known than pneumatic riveting. Many different machines have been devised by Mr Ralph Tweddell and his co-patentees, Messrs James Platt and John Fielding (p. 224), to perform nearly all classes of riveting that can be done by machine. These riveters are made in fixed and portable forms, actuated by a hydraulic pressure pump and accumulator. So many varied and advantageous details have been introduced into them by the patentees, that their full

description would occupy a treatise, and would be beyond the scope of my subject. At a moderate estimate the cost of riveting is certainly reduced one-fourth by their use, and the work is better done. The pressure is not that of violent impact, but is gradual, compressing the rivet throughout its entire length instead of merely turning over the tail, which is the case in hand riveting. Moreover, the work is silent, and this is a great advantage by comparison with the deafening noise made by several sets of hand riveters working in a shop at one time. Plates, too, can be closed more effectually in machine riveting than in hand work. Pressures also can be varied to suit rivets of different sizes and different lengths. The capacities and range of work possible to these machines have now become much extended: not only plain work, like bridge girders and boiler shells, are riveted thus, but fire-hole and foundation rings, the rings of boiler flues, cast iron man-holes, and seatings can be done with them. The number of rivets that can be inserted per hour depends entirely upon their position, and may range from 1,000 to 4,000 per ordinary working day. But everything depends on the class of work, awkwardness or otherwise, and tackle available, the employment of suitable cranes, or of makeshift tackle, and so forth. A portable riveter can be suspended from pulley-blocks, but this is an awkward and slow method. Properly a light wall jib-crane is employed, having a length of radius sufficient to cover the class of work likely to be done in the shop. The power is brought to the machine through flexible pipes. The pressure exerted on the rivet tail at the moment of closing varies from about 25 tons to 40 tons, dependent upon the diameter of the rivets and thickness of the plate, and the pressure can be varied in a single machine. Plate and girder work, and vertical, and Lancashire, and Cornish, and locomotive boilers do not present so great difficulties to the riveter as marine boilers. The latter being formed of thick plates, say from 1 in. to $1\frac{1}{4}$ in. in thickness, are very difficult to close properly by hand riveting. But the machine riveter, working to its maximum pressure, pulls the plates up close. Moreover, the pressure of the ram can be retained upon the rivet tail until the rivet is cold, and the risk of the plates springing back and opening, and stretching the rivet, can be thus prevented. Three individuals are required to work a machine riveter—a boy to heat the rivets, a man to move along and steady the machine, or work, as

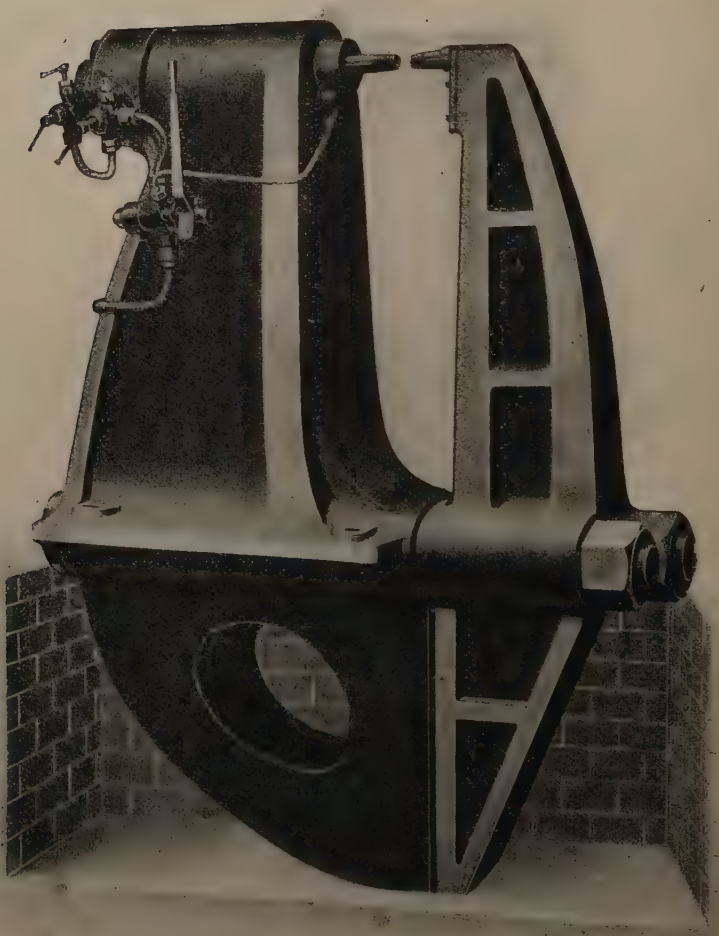


FIG. 238.

the case may be, and another to operate the lever of the machine.

A general idea of the forms of fixed and portable hydraulic riveters can be obtained from Figs. 238, 239, and 240. The first and second are made by Messrs Henry Berry & Co., of Leeds.

Fig. 238 is a 75 ton variable power riveter. The dies are in the centre of the ram. It has a gap of 7 ft. 6 in., and is capable of closing rivets with three powers, viz., 75, 50, and 25 tons, and the valves are so arranged that (without any complication) they can be adjusted in a few seconds to give any of the above pressures on the rivets.

The machine is very strong, the main frame being of cast-iron, with cylinder cast on,

Fig. 239.

or if preferred the cylinder can be made separate, of cast-steel, and firmly bolted and jointed to the main casting.

The holder-up is of Siemens cast-steel, planed and jointed, and firmly bolted to the main frame by means of massive forged steel bolts.

The ram is of forged steel, and the cylinders are all lined with phosphor bronze, the valves also being of the latter material. There is an arrangement for holding the plates together whilst the rivet is being closed.

Fig. 239 is a hydraulic portable riveter for bridge work. It has a gap of 15 inches, and is 34 inches wide, thereby being able to rivet parts of the bridge after the flanges are put into

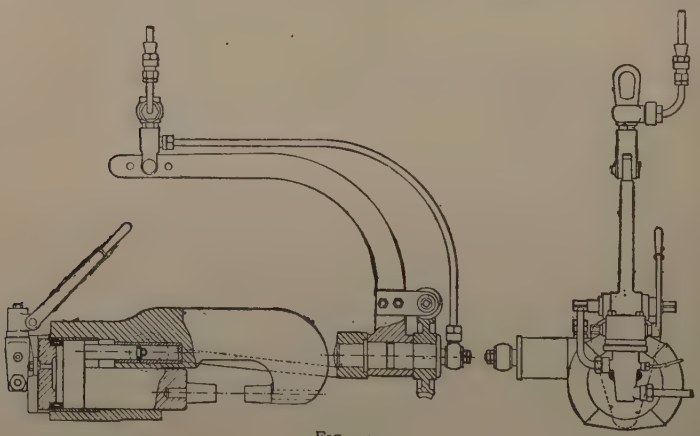


FIG. 240.

position. The machine is shown in two positions, and can very readily be put into any intermediate one. Three lugs are cast on, so that it can be hung in any fashion required.

Fig. 240 is a hydraulic portable riveter, "Bear" type, by Messrs Fielding & Platt Ltd., which is used for locomotive fire-door and foundation rings, &c. The body can be tilted in two directions, by either turning the worm gear at the end, or by angling the body upon its gudgeon pin, which is supported by an arm extending from the swivelling pin of the worm. The suspension link from which the bow depends is hollow, and conveys the water from the supply pipe. There is a constant-

pressure small pipe seen at the front of the cylinder for supplying the drawback cylinder, shown above the main ram. The power of the machine is 40 tons.

Pneumatic Riveting.—In Allen's pneumatic system, air is pumped from an air compresser into a receiver at a pressure of 80 to 100 lb. per square inch. The compressed air is brought from the receiver through wrought-iron piping along the shop, and thence through flexible indiarubber tubing to the machines. The riveter is suspended from the jib of a wall or travelling crane or other convenient support, and is operated by a couple of attendants. When a rivet is inserted, the riveter is adjusted until the pressure ram is brought into line therewith. Then the turning of a lever moves a valve in the valve-chest and admits the air behind the piston, and the forward motion of the piston is communicated through an arrangement of toggle levers to the plunger which carries the screw ram, to the end of which is attached the heading-cup. The movement of the top heading-cup, rapid at first, becomes more gradual towards the end of its stroke, so that the rivet is closed with a slow, steady squeeze. After allowing the pressure to remain on for about 15 seconds, to give the rivet time to cool, the air behind the piston is exhausted by moving the lever in the opposite direction, and the ram rises to its original position in readiness for the next rivet.

Although the pressure on the piston of the Allen pneumatic riveter is only 80 to 100 lb., yet the pressure exerted on the rivet tail at the moment of closing is about 30 tons. The gain in power is effected by the toggle joint arrangement. The greatest pressure is applied just at the termination of the stroke. For hand pneumatic riveters, *see* pp. 323-326.

Messrs De Bergue & Co. Ltd., of Manchester, who make the Allen riveters, have them in forty different sizes. Some of the largest range up to 8 ft. in the gap, with an effective pressure of 100 tons, capable of closing rivets up to $1\frac{3}{8}$ in. They may be worked by steam, if desired, as being fixed, there is no inconvenience caused in conveying the steam, as there is in the case of portable riveters.

In reference to the relative merits of hydraulic and pneumatic riveting, the latter seems to possess some advantages over the former—in two respects its merits are superior. In hydraulic riveting there is the trouble of freezing water in cold weather, and there is the leakage which results from worn leathers. But

the hydraulic is the more gradual, and therefore preferable on that account. It is in most general use.

Rivet Furnace.—The ordinary rivet furnace is not large enough for serving a hydraulic or pneumatic riveter. A small reverberatory rivet furnace is wanted, so that from 100 to 200 rivets can be heating at once on the hearth, free from contact with fuel, and to uniform temperatures. Scaling of the rivets must be prevented by lowering the damper, if necessary.

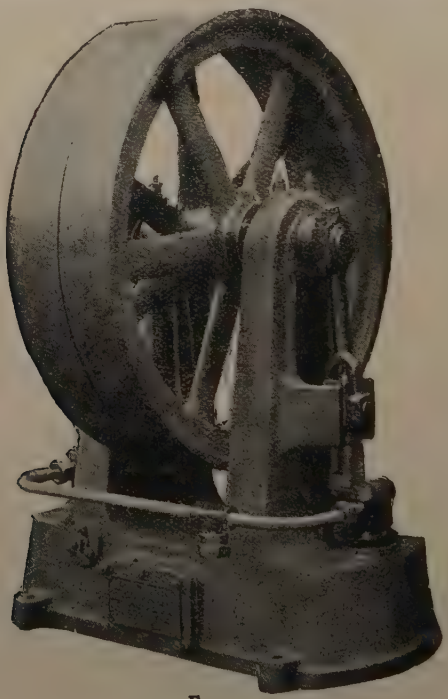


FIG. 241.

Description of Hydraulic Riveting Plant.—Since the method of riveting by hydraulic pressure is of so great mechanical and economical importance, I propose to conclude this chapter by giving a condensed account of the essential details of the plant employed in the work, illustrated with various machines constructed by leading makers. The late

Mr Ralph Tweddell invented the earlier machines. It is of course difficult to specify a complete plant suitable for general work, because shops deal so much in specialities. But the following remarks will be generally indicative of the nature of the selection of machines and plant for various classes of work.

First, as to pumps and accumulators, if the works are small, belt-driven pumps, as shown in Fig. 241, would be used, and accumulator, as shown in Fig. 242. If for a larger concern, horizontal belt-driven pumps, or a horizontal steam pumping engine, would be used. Duplex engines are now very commonly used in place of the crank engines, as they are simpler and less costly. For flanging marine boiler plates the machine, of which two views are shown at Fig. 329, Chap. XVII., would be used. Fig. 243 illustrates the Fielding riveter. For locomotive and stationary work the machine shown at Fig. 223, p. 201, would be required.

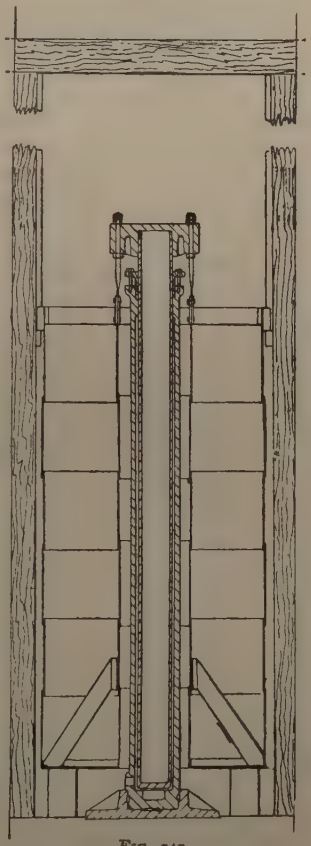


Fig. 242.

For riveting marine work, the plate closing fixed riveter, shown in Fig. 244, would be used. These are made with all gaps, from 4 ft. to 17 ft., and from 50 to 180 tons power. For lighter and stationary work other suitable machines may be used. These are made with gaps from 3 ft. to 16 ft., and from 20 to 60 tons power.

Fixed riveters require cranes to handle the work. Sometimes a tower with a travelling crane is provided, and a hydraulic jigger would be used for lifting the work being riveted. The other motions of the crane may be worked by hand, or by hydraulic power.

Portable riveting machines of various types are used for different works. They are usually carried on light cranes fixed to the wall, as shown in Fig. 245. Sometimes they are made to travel down the shop, being carried on girders on each side of the shop, or on rails on the ground. The hydraulic wall crane, Fig. 245, is a jib crane swinging in bracket bearings, which can be secured to a wall or to the columns of a building,

FIG. 243.

and is intended to carry any form of portable riveter. It is made from 16 ft. to 28 ft. radius, with a lift of 7 ft., and to lift 1 ton; but these dimensions and capacity are sometimes varied. The post is of cast-steel, and the jib consists of two steel channels, on which runs a carriage with a hand chain sprocket wheel and gear, to travel it along. A horizontal hydraulic

cylinder on the carriage operates pulleys and chains for raising and lowering the riveting machine, suspended from a bow

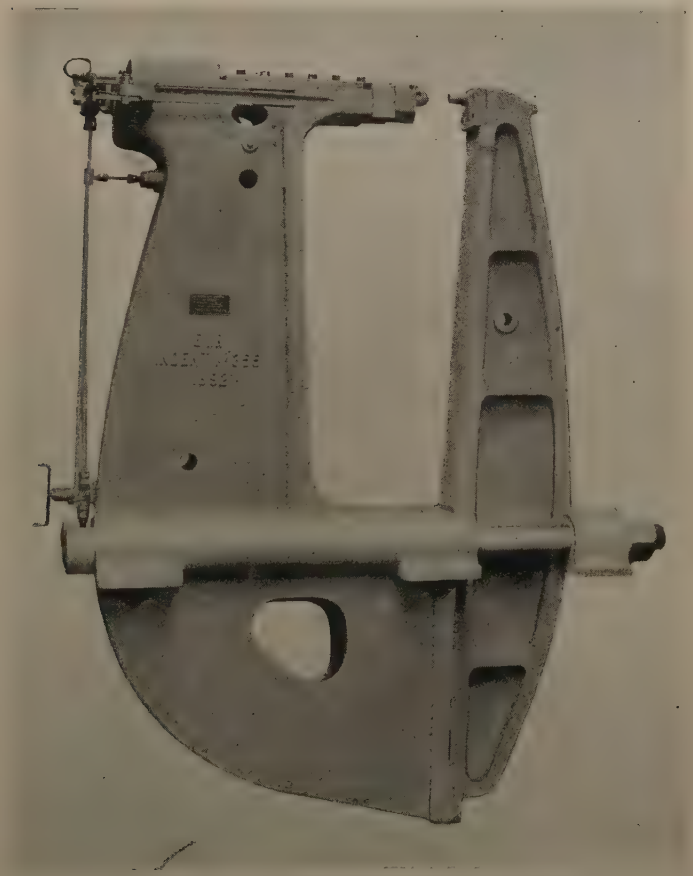


Fig. 244.

hanger. The pressure to lift, and also to operate the machine, is brought to a swivel joint fixed on the lower end of the crane post, and a pipe from the swivel is carried to a point near the middle

of the length of the jib, to which are connected two pipes with joints, the end of one pipe being connected to the carriage end

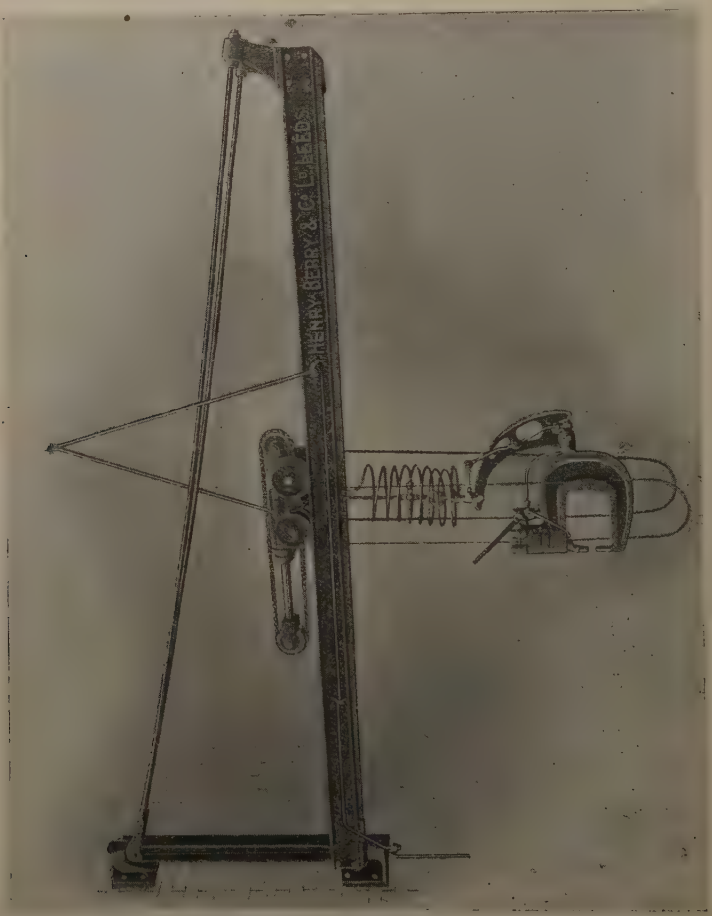


FIG. 245.

by a joint. These joints are packed with cup leathers, so that the pressure water can pass through them. From the jointed pipe on the carriage, a connection is made by a coiled copper

pipe to the hook of the hanger, whence a jointed pipe conveys the water to the gudgeon pin.

For locomotive fire-box work the portable riveting machine shown in Fig. 246 is used, and for tanks and tenders the machine shown in Fig. 247. For the Adamson seams another type of machine is used. And for girder work another class of machine, Fig. 248.

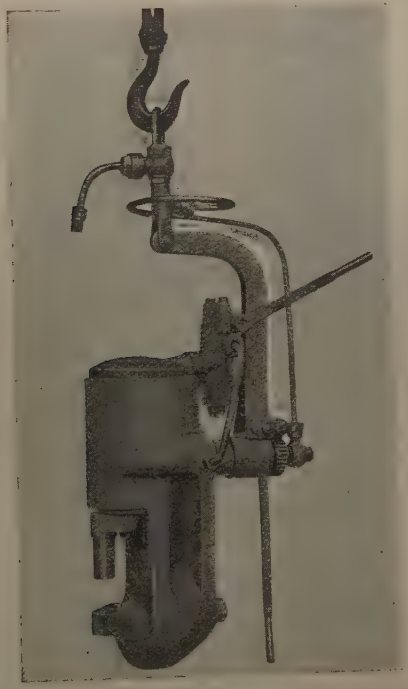


Fig. 246.

I will now give detailed descriptions of some of the machines just mentioned.

The illustration (Fig. 241) shows a vertical belt-driven pump, which consists of two single acting ram pumps, to work at a pressure of 1,500 lb. per square inch. The barrels are of

gun-metal, with gun-metal valves and rams, the crankshaft is of forged steel, the bearings have large wearing surfaces, and are all adjustable. The fast driving pulley is made with a heavy rim to form a fly-wheel. The framework is of cast-iron, the base forming a suction tank. The pumps run from 60 to 80 revolutions per minute.

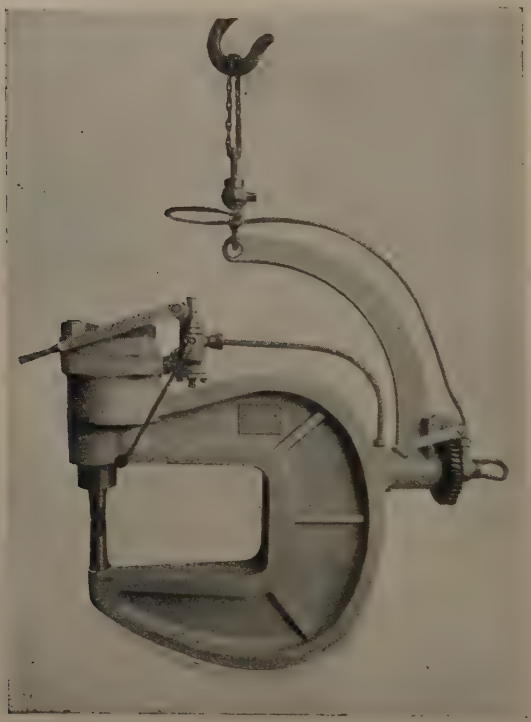


FIG. 247

The illustration, Fig. 242, shows a weight case accumulator in which the cylinder is fixed in the base plate, and the ram lifts the casing which contains the load of slag or heavy material to give the desired pressure. Guide rails are fixed to the wooden framing for guiding the casing. Wooden blocks are fitted in

the base for the weight case to rest upon. At the base in which the cylinder is fixed is a valve box containing two valves, the pressure water from the pumps passing over one and under the other into the cylinder. The lower valve can be lifted by a lever and spindle passing through the bottom of valve box.

The hydraulic flanger, Fig. 329, will be found described on p. 313.

Fig. 243 illustrates the Fielding portable riveting machine.

Fig. 248.

It is made with gaps varying from 15 in. to 60 in., and with powers from 10 tons to 50 tons. It consists of two cast-steel arms or levers hinged together at about two-thirds of their length from the riveting ends, in which are fixed the snaps or riveting tools. At the other end of one of the levers is fixed a cast-steel cylinder, and a gun-metal ram on the end of the other lever, working freely in the cylinder. The ram is turned and the

cylinder bored on a curve, or on portions of the arc of a circle struck from the centre of the hinge pin, so that the piston or ram moves in the cylinder in a circular path, and fits the cylinder, so as to steady and guide the riveting end of the levers. A U leather is fitted on the ram or piston, and the ram is pushed back by a small hydraulic cylinder fixed on the main cylinder. The operating valve is also fixed on the cylinder, and is arranged so as to automatically cut off the pressure water supply when the arms open to their full width at the cylinder end. The gudgeon or centre pin is fast on the cylinder lever, the ram part working loose.

The illustration, Fig. 244, shows one form of stationary riveting machine, in which the body or frame is of cast-iron, and the post or hob of cast-steel. It is of the plate-closing type, a section of the head of which is shown on p. 233. The post and body are held together by two large steel bolts and nuts. The ram or riveting slide fits in a cylinder formed in or fitted to the head of the body or frame, which is bushed with gun-metal. The slide in the ram is pushed back by a small cylinder and ram subject to constant pressure. The operating valve is of the piston type, and is fixed to the cylinder cover, with hand levers placed conveniently for the operator. The riveting tools are placed in sockets, one in the end of the ram and the other fixed on the post or hob.

The portable riveter, Fig. 246, is in principle the same as Fig. 247, but of smaller gap or opening, so that the machine will pass through the furnace mouth of a marine boiler to rivet the row of rivets round the opening. The hanger is arranged so that the machine can be rotated by the worm and wheel gear attached to a trunnion on the end of the machine. The pressure is conveyed from the lift down through a pipe alongside the bent arm of the hanger, to the trunnion, and through the latter to the operating valve.

In the direct acting portable riveter, Fig. 247, the body is of cast-steel in one casting, the cylinder is on one arm, and the fixed riveting tool on the other. The gudgeon at the back receives the bow hanger, which is set at any angle by worm gear, or the machine may be suspended alternatively from the eye-bolt at the rear. The gap is 2 ft., and the ram exerts a pressure of 40 tons, closing rivets up to 1 in. diameter. Machines of this class are employed on bridge, roof, and general constructional work; the depth of gap is varied to suit require-

ments. Machines with long gaps are not fitted with bow hangers, but with a form of stirrup, attached at either top, bottom, or end of the frame. The operating valve is of the piston type, and fixed near the cylinder, operated by a hand lever.

The hinged type of riveter, Fig. 248, is handy for work which cannot be dealt with by the bear class, owing to the fact of the cylinder being in the way of flanges, &c. In Fig. 248, the snaps are set at the ends of hinged levers, pivoted upon a pin, and forced apart at the opposite end by a ram in a cylinder, the end of the ram, which is fitted with a roller, pressing against a curved face on the lever.

With regard to the plate-closing riveting machines:—

In boiler work, the bringing of the plates together, and keeping them in close contact while the rivet is being squeezed up, is a very important feature. It might seem that they could be brought together by merely using a heavier pressure on the riveting dies. This is a mistake, as the increased pressure in many instances permanently injures the plates, while, as the full pressure does not come on them until the rivet is headed, some of the material of the rivet is squeezed in between the imperfectly closed plates, of course effectually preventing their afterwards being brought together at all. Besides this, unless the plates are in perfectly close contact, and are kept so during the operation of closing the rivet, every

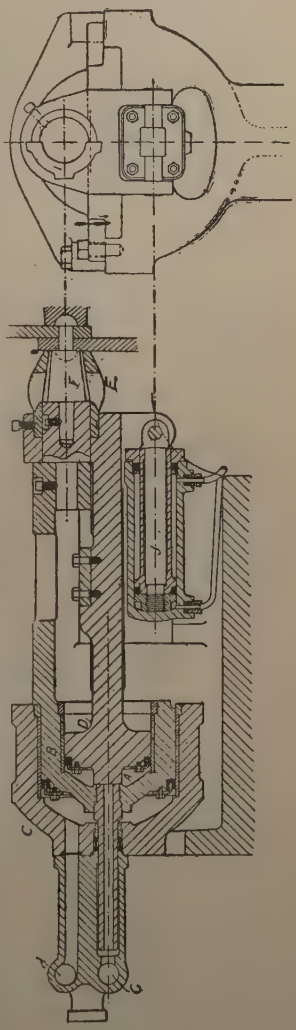


FIG. 249.

extra ton pressure put on over and above that necessary to crush up the hot rivet is wasted.

The introduction of hydraulic pressure riveting machinery by Mr Tweddell permitted a great improvement in the method of closing, over what was previously in use. Before riveting commenced, flat-headed closers were put in the die holders, and the boiler being slung up, the seam to be riveted was passed between these closing tools, and the service bolts tightened up. In common, however, with other devices since employed, this system had the objection of taking the pressure off the plates before commencing to form the rivets. The machine now referred to was designed to overcome this defect, while embodying several other recent improvements as well.

The essential action of Messrs Fielding & Platt's plate-closing riveting machine, shown in Fig. 244, p. 227, is illustrated in Fig. 249. The opinion of many engineers of great experience in boiler-making is that 80 tons, when divided into two powers, one for plate-closing, and the other for rivet-forming, is quite sufficient, and is probably more than equal to 120 tons applied without the plate-closing arrangement.

The section through the working cylinders shows the plate-closing cylinder A, contained within the movable riveting cylinder B, sliding within the fixed cylinder C. The ram D moves within A and carries the closing tool E, while the rivet snap F is attached to the end of B. G is the valve communicating with the accumulator and admitting water to the back of D. The mode of working is as follows:—Upon opening the valve G to the accumulator, the ram D moves forward the closing tool E, so that it presses the plates together. Valve H is then opened, letting water in to force B forward, and with it the cupping tool F. The area of the ram B being more than double that of the ram D, when pressure is admitted to it by opening the valve H, it forces part of the water contained in B back into the accumulator, until the cupping die closes the rivet. While this is being done, it will be evident that the pressure due to the area of D is still being exerted on the plate-closing tool E, thus keeping the plates pressed together. In the 150-ton machine this pressure amounts to 60 tons, the balance of 90 tons being exerted on the dies for forming the rivet. If the work is very heavy, by opening the valve G to exhaust, the pressure is released from A, and the whole 150 tons due to the main cylinder C is put upon the rivet head, but as this occurs after

the plates have been closed, and the rivet formed, "washering" is impossible. The actual time occupied in closing a rivet is not appreciably longer than with the ordinary machine. The plunger J returns the rams. The usual arrangements for adjusting the stroke to meet any variation in length of rivets, or thickness of plates, are fitted. It will be observed that the cupping tool is practically flush with the top of the cylinder, this object being obtained without cranking the die, or throwing any undue strain either on the die or the working parts.

In addition to the arrangements as described, the machine can also be used for lighter riveting work by not employing the large ram at all. This is accomplished by removing the closing tool and substituting a cupping die, and working the small arm D by means of the valve G. This is a great convenience, as with the lighter pressure and long gap a marine boiler furnace can be riveted up to the combustion chamber, besides which there is always odd work to be done in a boiler yard for which a comparatively small pressure will suffice. Another advantage of this machine is the facility it affords for doing flush riveting.

Dimensions.—With regard to the dimensions of the foregoing riveting machines, it may be helpful to give a few instances of the range of sizes and capacities. Referring to Fig. 247 (a machine by Messrs Rice & Co. Ltd., Leeds), other sizes of this class are made, as follows :—

Gap.	Power.
1 ft. 6½ in.	20 tons.
2 „ 0½ „	20 „
2 „ 6½ „	12½ „
2 „ 6½ „	20 „

In Fig. 248, also by Messrs Rice, the sizes range as follows :—

Gap.	Power.
2 ft. 6 in.	30 tons.
3 „ 0 „	30 „
3 „ 6 „	30 „
4 „ 0 „	30 „
4 „ 6 „	30 „

The plate-closing machines, Fig. 244, are constructed in the following standard sizes :—

Gap.	Power.
8 ft. 0 in.	40 tons.
12 „ 0 „	40 „
13 „ 9 „	40 „
16 „ 6 „	40 „
12 „ 6 „	50 „
14 „ 6 „	50 „
17 „ 0 „	50 „
13 „ 0 „	100, 60, 40 „

CHAPTER XIII.

TYPES OF RIVETED JOINTS.

Lap Joints.—Thinning Corners.—Joints made with Covering Strips.—Joints made with Angle-Iron.—Flanged Joints.—Furnace Tubes.—Girder-Work.—Compound Girders.—Built-up Girders.—The Single Girder.—Joints in Long Girders.—The Double Girder.—Heaters.—Division of Girders.—Brackets.—Jointing Vertical Members.—Diagonal Members.

I WILL now consider the various types of riveted joints made use of by platers and boiler-makers. There are several kinds of joints in occasional use only, which I must omit; but those which I shall illustrate are in common use, and are of standard and recognised types. It is astonishing how large a number of serviceable riveted joints can be made between plates, angles, tees, and flanged ends. I will first take the typical joints used chiefly in boiler work, and afterwards those employed mostly in plated, constructional, and girder work.

Lap Joints.—The simplest form of joint is the lap, Figs. 250-251. Plates are simply overlapped to an amount sufficient for the insertion of the row, or rows, of rivets, and giving sufficient margin of plate beyond. The amount of lap is usually one and a half times the diameter of the rivet, measured to the centre of the rivet, from the edge of the plate. The single riveted lap joint, Fig. 250, is too weak to stand heavy pressures when carried longitudinally—that is, in the direction of the cylindrical axis of a boiler. Except in very small boilers, therefore, double riveting, Fig. 251, is adopted in longitudinal seams. For circumferential seams, however, single riveting makes a strong joint.

Rivet joints may fail (1) by the rivet shearing across; (2) by the plate in front of the rivet crushing; (3) by the plate tearing across the centre line of the rivets where it is weakened by the

rivet holes; (4) by the plate outside the hole breaking in the direction of the edge; (5) by the plate outside the rivet hole being forced out bodily.

The strength (1) of a rivet to resist the strain tending to shear it off is equal to the area of the rivet, multiplied by the strength of the iron, the shearing stress being considered equal to the tensile stress in iron, or in the proportion of 23 to 28 in steel.

The resistance (2) of the plate to crushing in front of the rivet is equal to the diameter of the rivet multiplied by the thickness of plate and the strength of the same.

The resistance (3) of the plate to tearing along the line of

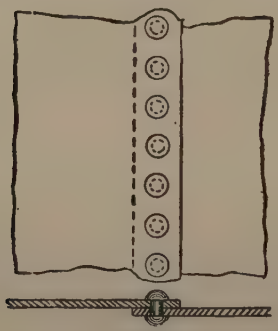


FIG. 250.

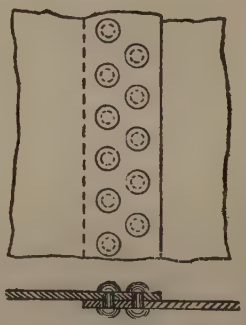


FIG. 251.

rivet holes is found by subtracting the diameter of the rivet from the pitch, multiplying by the thickness of the plate in inches, and the product by the strength of the metal.

The strength to resist (4) the tendency of the plate to split in front of the rivet is estimated by regarding the metal in front of the rivet as a girder whose length is equal to the diameter of rivet, and its depth equal to the distance between the rivet and the edge of the plate. This kind of rupture is frequently met with in boiler work.

The form of fracture (5) is rarely met with. In it the resistance of the plate is equal to its shearing strength multiplied by the area sheared.

The loss of strength due to riveting is variously estimated, and is dependent upon the nature of the plates, and the means adopted for piercing the rivet holes, and the pitch and disposi-

tion of the rivets. There is, of course, the direct loss sustained by the weakening of the plates due to the section of metal removed, but I refer now to the influence which the practice of punching, drilling, and rymering exerts upon the structure itself. Thus it may be stated generally that the tensile strength of drilled plates is uninjured by the process, that punching injures plates most, but that when punching is followed by rymering the injury done is of comparatively slight amount. Drilling holes, and leaving the sharp arris around the edges, while retaining the strength of the plate unimpaired, is found to have a tendency to shear the rivet more than a punched hole.

The injury done to plates by punching is also affected by the shape of the die, which ought to have a sufficient amount of clearance; by the brittleness or ductility of the plates themselves, by the practice of annealing subsequently to punching, and by the abuse of the drift; so that no hard and fast rules can be laid down. With punched and rymered work performed with special precautions, and in soft plates, and in drilled plates not drifted, there is no appreciable loss of tensile strength.

The most important factors to be considered in estimating the strength of riveted joints are the forms of the joints themselves. In their order of descending merit they are:—1. Solid plate; 2. Double riveted, with double butt straps; 3. double riveted, lap joint; 4. Double riveted, with single butt straps; 5. Single riveted lap joint.

For the values of these, various percentages are given, since the conclusions of different experimentalists show considerable variations, and results are vitally affected by conditions of workmanship as well as of wear and tear. Hence therefore the need of large factors of safety in plated works. The tables in the Appendix give suitable proportions for the common joints used by boiler-makers and platers for iron and steel plates and rivets, and these give good percentages for the relative strengths of plate section and rivet section.

There are several other types of riveted joints besides these, as treble-riveted with various arrangements of rivets, zigzag and chain, with and without alternate rivets omitted in certain rows, Both the Board of Trade and Lloyd's Register give standard rules for the determination of pitches, areas, &c., so that the percentages of plate section and of rivet section shall be suitably proportioned, but the consideration of these matters is beyond my purpose. I give in Tables IX. to XVII., in

Appendix, suitable proportions for the ordinary rivet joints used in the shops.

Thinning Corners.—When lap joints have to overlap one another, then one of the plates has to be thinned down at the corner. Fig. 252 shows such a corner thinned down, and Figs. 253 and 254 two joints made in this way, the first with single, the second with double riveting. It will be observed that a rivet is put through the thinned-down corner, and that it is the middle plate of the three which is thinned. When riveted between the two outer plates and caulked, the joint is perfectly sound.

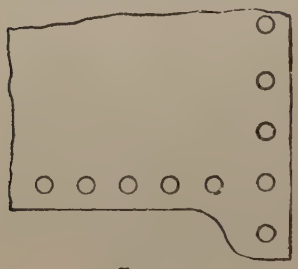


FIG. 252.

Joints made with Covering Strips.—When plates abut by their edges, joints are made by means of covering strips, Figs. 255, 256, 257, the first being single riveted, the second

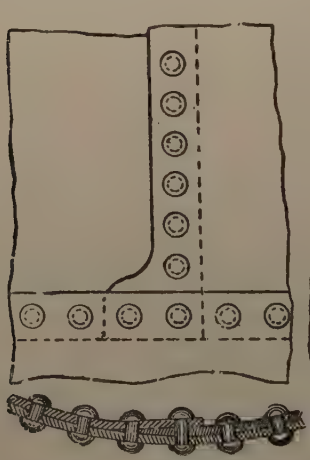


FIG. 253.

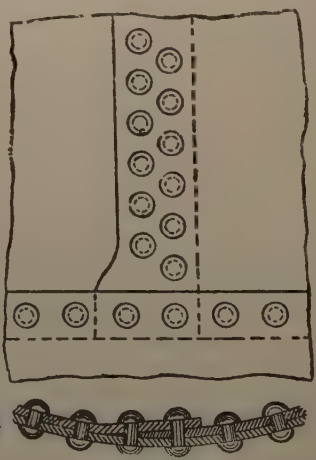
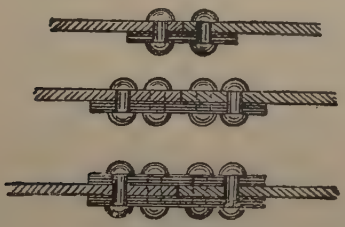


FIG. 254.

and third double. The first is like the single-riveted lap joint—very weak; the second is better. But in any case single strips should never be put inside a boiler, but outside; because if put

internally the tendency of the pressure is to open the joint, and the often-repeated opening and closing results in grooving of the plates. Better still is it to have double strips, one external, the other internal (Fig. 257).

Joints made with Angle-Iron.—There are several methods of uniting plates not in the same plane. Fig. 258 shows joints made with angle-iron. They are used in fastening the ends, or tube-plates, to the shells of horizontal boilers. The angle-iron ring is bent and welded up, and the barrel and plates riveted to its flanges. A shows an internal ring used for the back-end plates, B an external ring used for the front-end plates.



FIGS. 255, 256, 257.

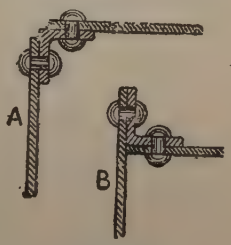


FIG. 258.

FIG. 260.

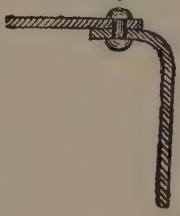


FIG. 259.

Since steel has been used for boilers, a growing practice is to dispense with the angle-iron ring, and save one seam and set of rivets by flanging the end-plates and riveting them direct to the boiler barrel (Fig. 259). The same method is adopted in the ends of marine boilers, in the tube-plates of locomotive boilers, and in the crowns of vertical boilers. Always, however, the radius over which the plate is flanged should be as large as practicable—say, not less than three to four times the thickness of the plate itself. Both the angle-iron and the flanged form of joint are also used between the ends of the fire-tubes and the end plates of Cornish and Lancashire boilers.

Flanged Joints.—Fig. 260 shows the upper end of the outer fire-box of the shell of a locomotive boiler doubly flanged, the part A receiving the sheet for the outer fire-box, the part B the boiler barrel. This is a neat bit of work if done by hand, but easily accomplished when done in dies under a hydraulic press.

Figs. 261 and 262 show two modes of jointing the uptake of the chimney of a vertical boiler to the shell crown, the first being by means of an angle-iron ring, the second by flanging

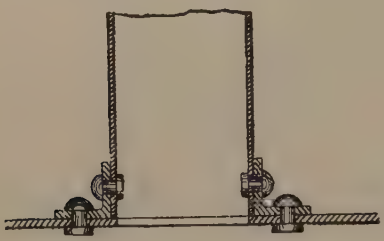


FIG. 261.

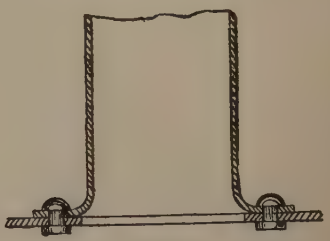


FIG. 262.

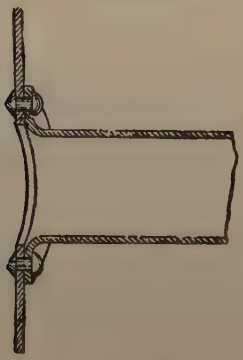


FIG. 263.

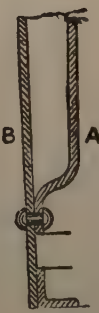


FIG. 264.

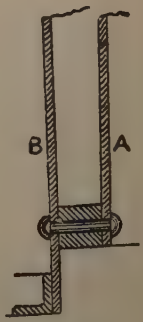


FIG. 265.

the tube. Fig. 263 shows the jointing of a cross tube to the sides of the fire-box shell of a vertical or horizontal boiler, always by flanging, the use of angle-iron being quite inadmissible in such cases.

Figs. 264 and 265 show two methods by which the fire-box shells of vertical boilers are united to the boiler shells at the bottom. The first is done by flanging the fire-box shell A outwards, and riveting it directly to the outer shell B. The second

is done by riveting the two shells together through a foundation ring of wrought-iron, which keeps the shells at the correct distance asunder.

Furnace Tubes. — The remaining figures illustrate methods of uniting the rings of furnace tubes. They both afford strength circumferentially, enabling the tubes to resist collapsing pressure, and at the same time they permit of longitudinal expansion. Fig. 266 is a hoop seam. Fig. 267 is an Adamson's flanged seam, A in the latter being a caulking ring.

FIG. 266.

FIG. 267.

FIG. 268.

FIG. 269.

FIG. 270.

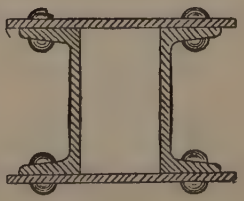


FIG. 271.

The disadvantage of Fig. 266 is that the rivet-heads are exposed to the action of the flame, which is always objectionable, and to be avoided whenever practicable.

Girder-Work.—Coming now to plated and girder work, the joints used differ in many respects from those which are employed for boilers. Flanging, so commonly resorted to in boilers, is never done in girders, neither is caulking. Lap-joints of the same type as those used in boilers are not employed,

neither are butt strips of the same type, though fish plates or cover strips are largely used. Beginning with simple types, let us trace the various methods of union adopted in built-up girder work.

Compound Girders.—All girders of large dimensions are built up of plate and angle. But small girders are usually constructed of joists, variously united, then termed compound girders.

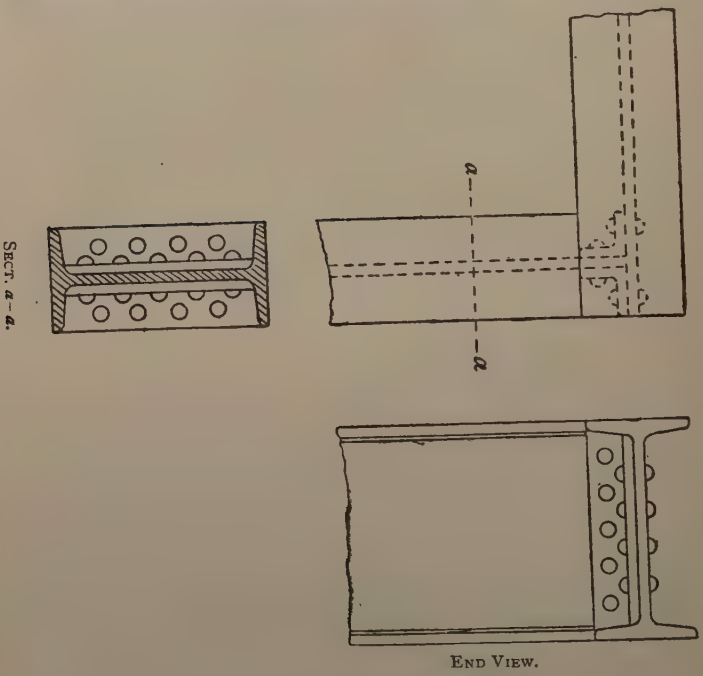


Fig. 272.

Plain rolled joists are commonly used as girders. Or two joists superimposed are riveted together (Fig. 268). Or two joists (Fig. 269) are united side by side with top and bottom plates. Three joists are often similarly compounded. Again, girders are built up vertically with three joists, or both vertically and horizontally at once. Frequently a broad girder is made by riveting top and bottom plates on a single joist, to give greater

bearing to the surface (Fig. 270). Sometimes girders are compounded with channels and plates in the manner shown in Fig. 271. By means of these and similar devices cheap girders are built up of moderate dimensions at the minimum of cost. Fig. 272 shows how a framed structure may be made with joists by means of angles riveted in the corners. Still, there is relatively little done in this way in engineers' good work, the supply of these being chiefly in builders' materials. In engineers' girder work for bridges, gantries, and other structures, plate and angle, or tee, are almost invariably made use of.

Built-up Girders.—Girders built up of plate and angle may be single or double. Fig. 273 shows a single-plated girder, Fig. 274 a double one. We will look at these figures in detail.

The Single Girder.—Taking first the single girder, Fig. 273, A is the web, B the top flange, C the bottom flange, of iron or steel plate. There is scarcely any rigidity in these plates in themselves, and though there is much strength in the web depthwise, it would camber sideways without the aid afforded by the top and bottom plates. These, moreover, possess little strength in the direction of their thickness; but they are strong and rigid sideways when united to A. The web and the flanges, therefore, are arranged in the best way for mutual support. They are united by means of the angles D, and these also afford support to the overhanging portions of the thin flanges B and C.

In a deep girder, however, the web A would buckle or bulge in the large unstayed area between the inner edges of the angle irons D D—that is, though it would not curve in the longitudinal direction, for that is prevented by the top and bottom flanges, it would bulge or belly in the vertical direction. The deeper the girder, the greater would be the amount of this crinkling or corrugation. To prevent this, stiffeners, E E, G G, of tee, or F F of angle-iron, are riveted at intervals down the sides of the girder. F F in this case also serves the purpose of an end flange. The stiffeners take two forms. They are either flat like E, or they are set down like G. If set down, their set-down portions fit over the angles D, and their faces lie directly upon the web A. This gives some extra work in the boiler shop, and an alternative practice, therefore, is to keep the stiffeners level, and insert plates H of the same thickness as the webs of the angles between the stiffeners and the web.

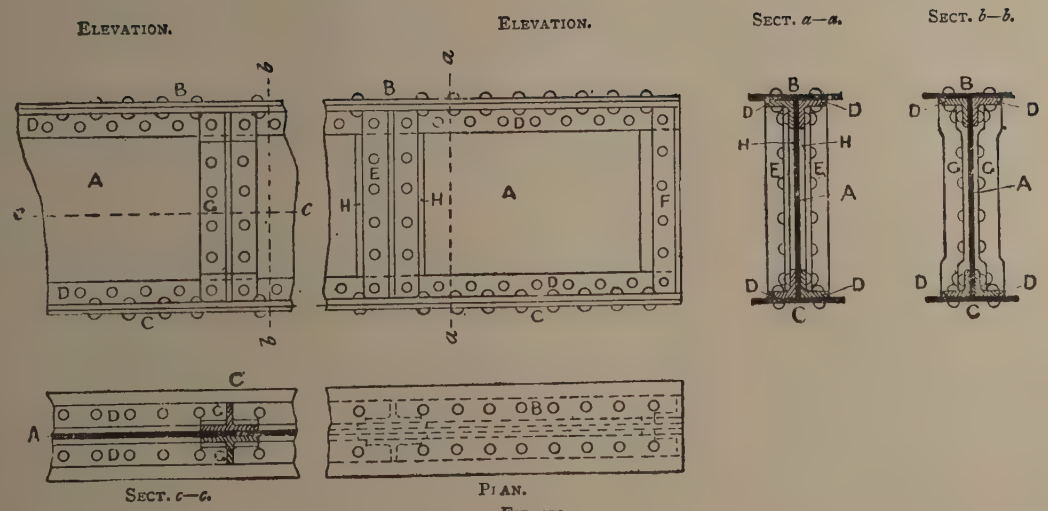
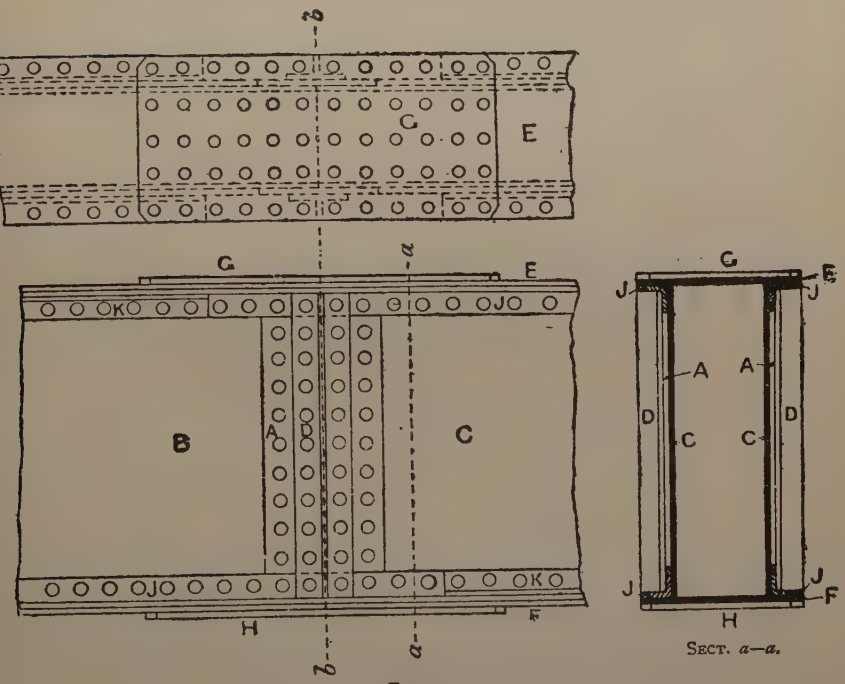


FIG. 273.

These are usually made $\frac{1}{2}$ in. or $\frac{3}{4}$ in. wider than the webs of the tees or of the angles, in order to impart a neat appearance to the joint, a definite amount of lap looking better than a joint which is neither flush nor lapping.

Joints in Long Girders.—But another matter arises in the making of a long girder: the necessity for making joints between the plates of which the web is composed. This is



SECT. *a—a*.

FIG. 274.

necessitated by the limiting sizes of plates, a subject which was treated in Chap. V. It is usually cheaper to make end joints between plates obtainable at the average prices than to incur the extra cost of plates exceeding the limiting dimensions. Such a joint as that shown in Fig. 275, made by riveting a tee-iron across the joint, would not be strong enough for

deep girders, notwithstanding that it is employed in some classes of work. A girder joint is made with a fish plate or covering strip A, Fig. 276, riveted to the abutting webs B and C of the girder. The angle-irons D and E also cover over the joint, and are riveted to the webs. Frequently, too, though not always, a tee-iron is laid upon the covering strip, and the rivets pass through tee, strip, and web. Fig. 274 shows such a joint, D being the tee-iron, and A the covering strip uniting B and C.

FIG. 275.

The Double Girder.—This figure also illustrates the construction of a double girder, having two webs united with top and bottom flanges E and F, and covering plates G H, uniting the top and bottom flanges E F, which are jointed with butt joints, along the line *b b*. The angles J assist in making the joints good, by being made to pass over the joints. Cover-

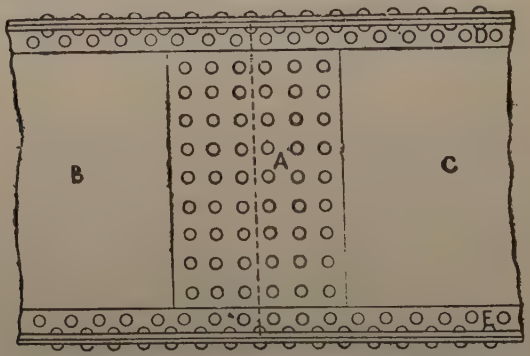


FIG. 276.

ing angles K pass over the joints of J, and are riveted through the main angles J and the web. When box-girders are of large dimensions, it is usual to rivet diaphragms between the webs and flanges. Diaphragms were shown in Chap. IX., Figs. 177, 178, p. 167.

When making double girders, the angles are riveted to their vertical plates first. Afterwards the horizontal plates are riveted to the horizontal webs of the angles. The risk in this work is

that the girders will be winding when finished, in which case correction is difficult or impossible, except by cutting out a number of the rivets, and going over the work again. It is necessary, therefore, to exercise a careful check upon the work while it is proceeding. The proper way to do so is to use the spirit-level in accompaniment with a straight-edge, the use of

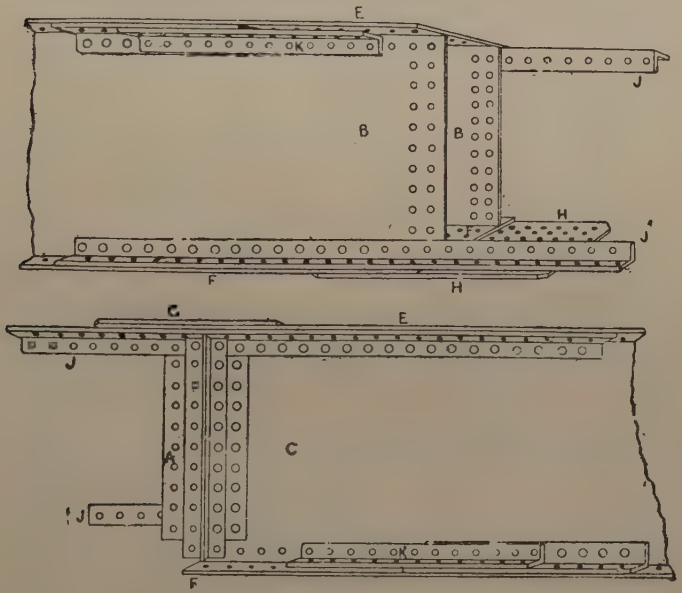


FIG. 277.

the latter being necessary to afford a sufficiently long base for the level. The straight-edge is carried across the edges of angles or of flanges, as happens to be most convenient, and the girder will be blocked up in a perfectly parallel position, in which it must remain while the riveting is being done. In a previous chapter I remarked upon the necessity for levelling and straightening all plates and angles. If this is not done, no other precautions will make a true girder; and if this is done, and the work is not levelled and taken out of winding while the riveting is being done, neither will the girder be true.

Heaters.—Heaters are used very freely in the boiler shop for the purpose of effecting slight local adjustments and settings of work. A heater is a lump of iron having sufficient mass to retain enough heat to raise considerably the temperature of the metal upon which it is placed. It may be 10 in. or 12 in. long, by from 3 in. to 4 in. square, or perhaps 5 in. or 6 in. wide, by $1\frac{1}{2}$ in. or 2 in. thick. It is made nearly white hot, and laid upon or against the portion which requires to be set or adjusted, and is kept there until nearly all its heat is imparted to the work. It is then removed, and the work set with the hammer as required. In strictness it is not good practice, because the metal rarely gets beyond the black heat, at which temperature it is injudicious to do any hammering or bending. But actually it is the only practicable method available after work is put together. As the setting usually wanted in such cases is but slight, there is probably no serious harm done.

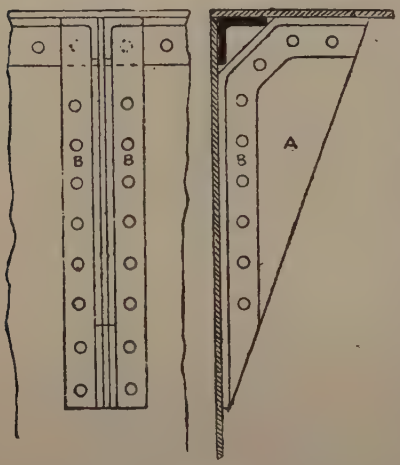


FIG. 278.

Division of Girders.—Long girders, being too lengthy for transport, are divided at the joint. Fig. 277 is drawn to represent in perspective a double girder, the parts of which are being either drawn apart or put together, the right hand end of the upper part of the figure matching the left hand end of the lower part When riveting up the girders in the shop, there are a number of the rivets omitted. During the temporary erection of the work for testing, their holes are filled up with bolts and drifts put in alternately; the rivets are not put in until the final erection of the work in place. The sections in which the rivets are omitted are usually upon opposite sides of the girder. Thus the angles J J J J project, two from B B at

diagonal corners, and two from C C at diagonal corners. So with the covering plates, G projects from C C, and H from B B. When brought together, B B abut against C C; E and E abut, and also F and F. J J J J pass along underneath the covering angles K K. G covers the joints of E E, and H the joints of F F, and the cover plates A A (the farther one of which is not seen in the figure) slide over B B. The joints are pulled up tight, and the rivets then put in.

I will now run over various forms of joints made use of in the construction of girder work in various structures.

Brackets.—Figs. 278, 279 show two plain brackets used to support and strengthen overhanging parts. Fig. 278 is made by cutting a piece of plate A to a triangular outline to fit against the vertical and horizontal faces of the work, and across the edges of the angle in the main structure. Then angles B B are bent and riveted to A. It is easier to fit angles like B B across the edges of an angle than to set them around to lie close into the main angle. Fig. 279 shows a parallel bracket with bevelled ends, used for a heavier class of work than the previous figure. There is a web A, and angles B B, to stiffen it. The bracket is united to the main structure by means of angles C C, riveted through the web through thickness strips D D.

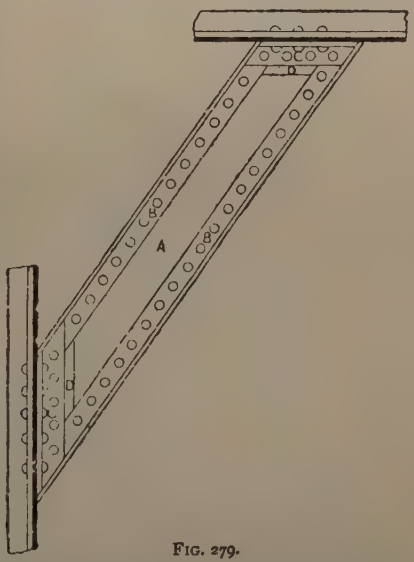


FIG. 279.

Jointing Vertical Members.—Fig. 280 shows the method of jointing vertical members to a box-girder. A is the box-girder, made, as already described, with webs, flanges, angles, and stiffeners. B B are two vertical webs, stiffened with

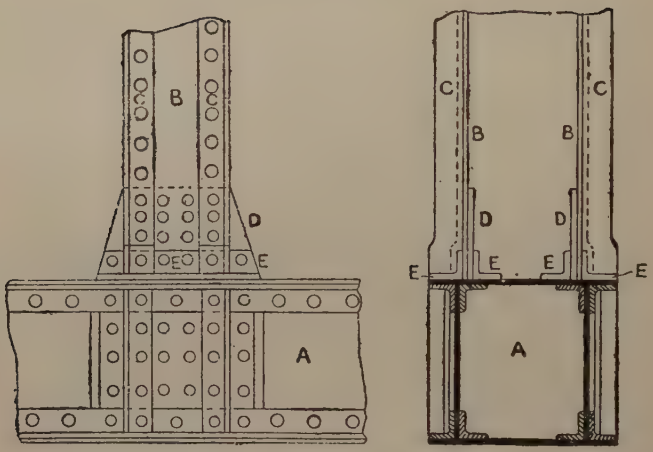


FIG. 280.

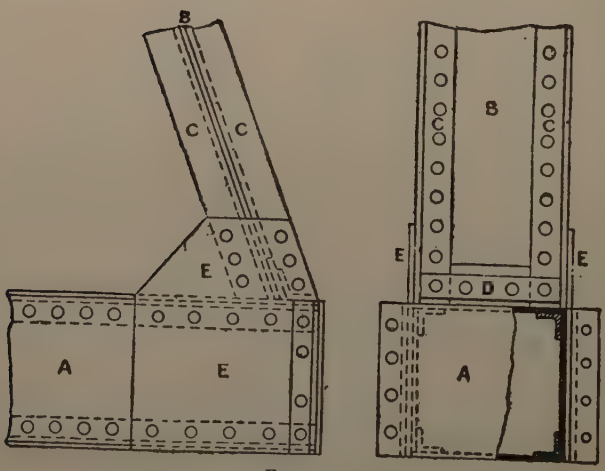


FIG. 281.

angles C C. These webs and angles are riveted to gusset-plates D D, which are in turn riveted to the top flange of the box-girder with angles E E.

Diagonal Members.—Fig. 281 illustrates a single-plated girder, fixed diagonally upon a box-girder. The box-girder A is shown in side view, partial end view, and in partial cross section, the end view showing a piece of plate covering the end, partly broken. The single-plated girder is made of plate B,

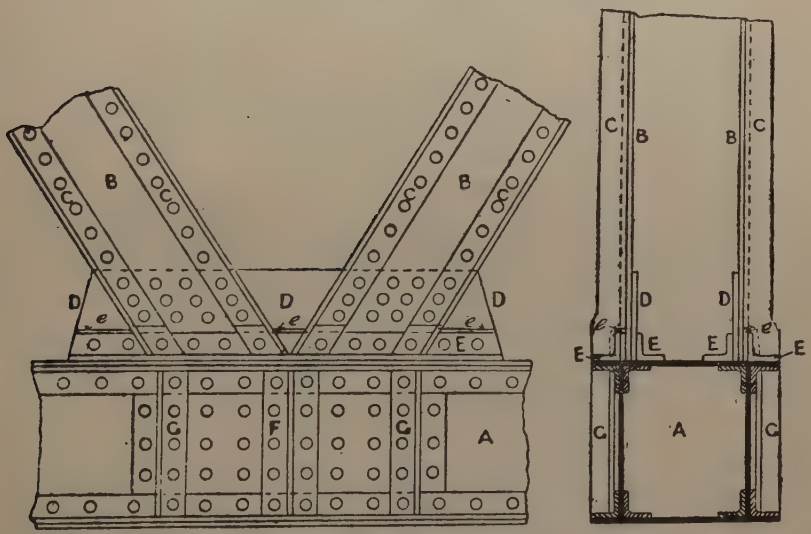


FIG. 282.

and angles C C; a bottom angle D, lying against a piece of plate, is riveted to the box-girder. But steadiness is imparted to the joint by means of the gusset-plates E E, which pass down the entire depth of the box-girder, being riveted to its side webs, and coming far enough up the sides of the diagonal girder to receive a number of rivets—six on each side in this illustration.

Fig. 282 illustrates the jointing of four diagonal struts to a box-girder A. The struts are built of plate B, and angles C. They are riveted to gusset-plates D, which are in turn riveted

to the box-girder with angles E E. Note that stiffeners of tee-iron F, and of angle G, are riveted vertically down the sides of

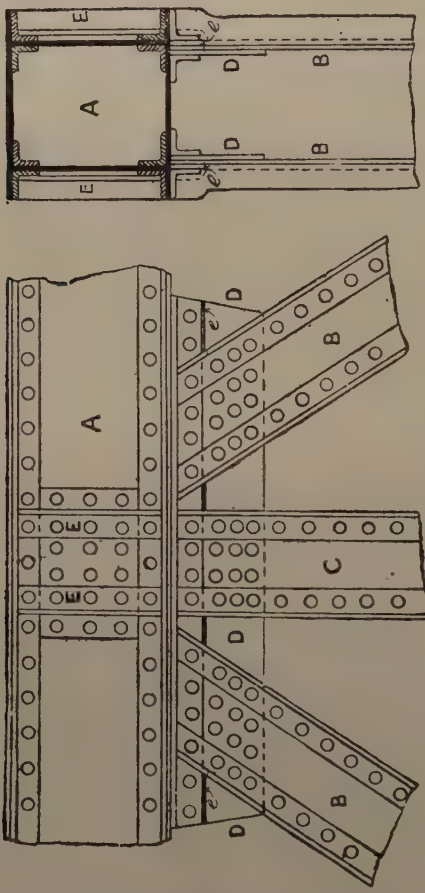
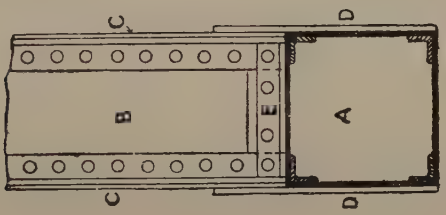


FIG 283

the box-girder to receive and sustain the extra stresses transmitted through the diagonals. *e e* are packing pieces of the same thickness as the webs of C C, behind the outer angles E E.

Fig. 283 shows a box-girder A, supported by two pairs of diagonals B B, and a centre member C. These are all attached to the gusset-plates D D. Stiffeners of angle-iron E E are riveted to the box-girder. *e e* are packing pieces.

Fig. 284 illustrates modes of fastening adopted in some framed structures. A is a box-girder, B a perpendicular



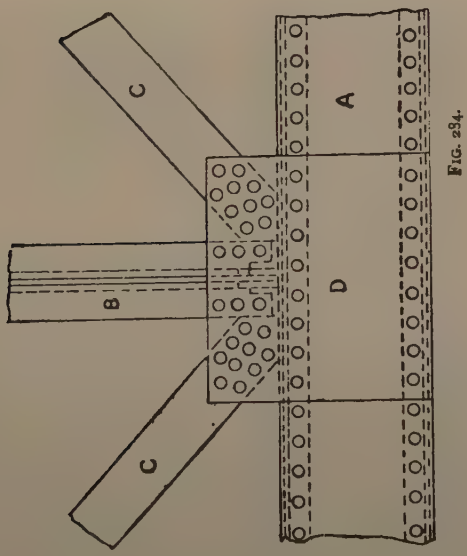
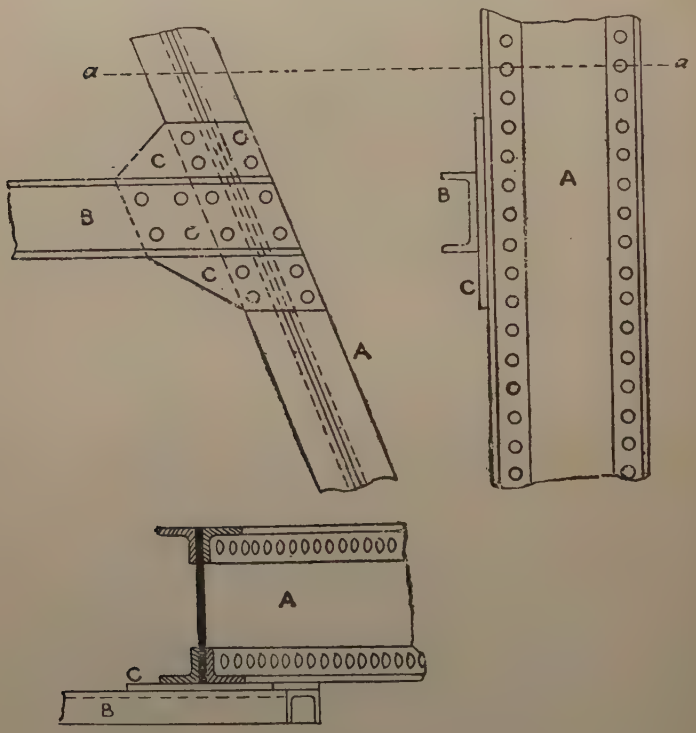


FIG. 284.

member built up of plate and angle, and C C diagonal ties formed of plain flat bars; C C are riveted to gusset-plates D D,

which, in turn, are riveted to A, B; B in addition is riveted to A with angles E.

Fig. 285 shows the union of a diagonal strut A, with a cross-beam B, through the medium of a gusset-plate C. A is formed



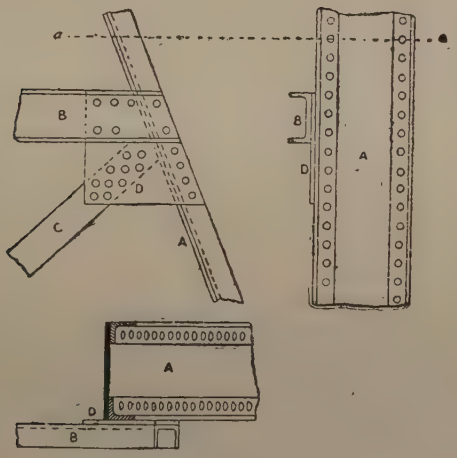
SECT. *a—a*.

FIG. 285.

of plate and angles riveted on both sides, B is a channel, C is riveted to the angles on A, and B is riveted to C.

Fig. 286 represents the union of a diagonal strut A, with a cross-beam B, and diagonal strut C. A is formed of plate and angles riveted on one side only, B is a piece of channel iron,

and C is a piece of flat bar. The gusset-plate D affords ample rigidity to the parts riveted to it; B, C, and D might be duplicated on the opposite side of A in work subject to heavy stress.



SECTION *a—a*.

FIG. 286.

This is a cheap and efficient type of joint. In all these figures the edge views of the rivets are omitted to avoid unnecessary crowding of lines.

CHAPTER XIV.

ESTIMATION OF LENGTHS OF MATERIAL.

Variations due to Modes of Working.—Shop Rules for Plain Circular Rings. —For Angle-Iron Rings.—External and Internal.—For Tee-Iron Rings. —Elliptical Rings.—Prices of Work per Ton.—For Riveting.—For Flanging.—For Bending and Welding Angle-Irons.—For Cross Tubes.

Variations due to Modes of Working.—The correct estimation of the lengths of material wanted for a given job is a frequent source of anxiety to the boiler-maker. His work is not like doing a sum in arithmetic, where, if you happen to make a blunder, you can rectify it by changing a few figures. If he makes a blunder in calculation, it means wasting or spoiling material, or involving extra work; and, if very serious, possibly dismissal. Hence the care with which lengths have to be estimated. Difficulty does not occur in straight plain work, but in the formation of rings and frames of various shapes. To a man accustomed to deal only in figures it would seem the simplest possible task to estimate the length of material required to produce any form required. So it is in the case of rings and frames of plain rectangular section. The difficulty comes in mostly in the case of other sections, chiefly those of angles, tees, and the other lesser-used sections.

I will devote a few pages to these subjects, taking plain plates, then rings of plain section, then rings of angle and tee sections. First, as regards plain plates.

When a boiler, square plated, that is, one built in parallel rings, is ordered to a given diameter, say 5 ft. 0 in., the diameter is usually taken as that of the inside of the smaller rings in the shell.

To determine the sizes of the plates to be used, a table of diameters and circumferences is consulted, and the lengths of the plates obtained at once, taking care to make due allowance

for the thickness of the plate, and the overlap of the seams. The amount of overlap is usually three times the diameter of the rivet for single riveting, and five times the diameter for double riveting. Of course in the case of butt joints, no such addition is made to the circumference given in the table.

In telescopic plating the diameter is taken at the smaller end of each ring. The circumferences are taken from the table as before. Such plates form conic frustra, and the method of marking them is described on p. 268. This is simple enough, but the case is different when rings of angle and other sections are concerned.

Tables of diameters and circumferences alone, without other allowance, will not give the correct lengths for these rings. And the heating of the sections also comes in to complicate the problem. Differences will be found in angles cut to the same length, if bent differently. A ring bent in short heats will generally come out longer than a similar bar bent at one heat. In all this class of work, whatever rules are made use of, a deal of experience must come in to diminish the risk of error.

Shop Rules for Plain Circular Rings.—Even when tables of diameters and circumferences can be utilised, workmen have often some rule of their own which is different from that of the mathematician, but which nevertheless works out all right. Thus a shop rule for the circumference of a ring of plain section is:—Three times the inside diameter + three times the thickness, + $\frac{9}{16}$ in. for each foot of circumference. Apply this roundabout rule, and the result will be substantially the same as,—diam. × 3.14159. Take, for example, a ring measuring 2 ft. 0 in. internal diameter, by 2 in. thick. The *mean* diameter will be 2 ft. 2 in., and 26 in. × 3.14159 = 81.68 in., or 6 ft. $9\frac{5}{8}$ in. mean circumference. Now apply the shop rule of thumb given above:—2 ft. 0 in. internal diameter, × 3 = 6 ft. 0 in., + three times 2 in. = 6 ft. 6 in. + $6\frac{1}{2}$ times $\frac{9}{16}$ = 6 ft. $9\frac{5}{8}$ $\frac{1}{32}$ in. And this is a rule which I have known regularly used in the shop, where the calculation—diam. × 3.14159, requiring the use of decimals—would have presented an insurmountable difficulty.

Angle-Iron Rings — External and Internal.—In the calculations for the lengths required for rings of angle and tee, the mean diameter is not taken at all; but a mode of measurement is adopted that would puzzle a mathematician, but the accuracy of which is borne out by shop practice. Still there are slight variations in the rules adopted by different

workmen, but not sufficient to make any very material difference in results. I will give two or three separate rules in use, with examples.

Angle-iron rings are either external or internal. Hence the rules for the estimations of the lengths necessary to bend the

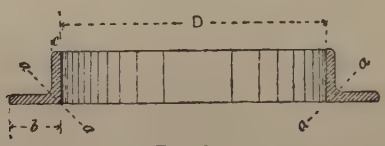


Fig. 287.

rings are precisely the reverse of one another. I will give rules for external rings, Fig. 287, first.

(1.) To the interior diameter D add twice the diagonal thickness measured on the line *a-a*, and multiply the sum by 3.14159. (2.) Multiply the diameter D by 3.14159, and add to the product three times the diagonal thickness measured on the line *a-a*, and once the width of the flange *b*. (3.) Add to the diameter D, one thickness of the web *c*, and one-third the width of the flange *b*, and multiply the product by 3.14159. (4.) Multiply the diameter D by 3.14159, to the product thus obtained add six times the diagonal thickness on the line *a-a*.

Note.—Welding length of $\frac{3}{4}$ in. or 1 in. is always added in addition to the rules given.

Let us see how these rules work out. In Fig. 287 let diameter D = 18 in., the thickness on the line *a-a* = $\frac{7}{8}$ in., the width of flange *b* = 3 in., and the thickness of web *c* = $\frac{1}{2}$ in.

By rule (1) 18 in. + ($\frac{7}{8}$ in. × 2) × 3.14159 = 5 ft. 2 in. long.

By rule (2) 18 in. × 3.14159 + (3 × $\frac{7}{8}$ in.) + 3 in. = 5 ft. 2$\frac{1}{8}$ in. long.

By rule (3) 18 in. + $\frac{1}{2}$ in. + 1 in. × 3.14159 = 5 ft. 1$\frac{3}{4}$ in. long.

By rule (4) 18 in. × 3.14159 + (6 × $\frac{7}{8}$ in.) = 5 ft. 1$\frac{3}{4}$ in. long.

As from $\frac{3}{4}$ in. to 1 in. is usually allowed for welding, and as slight variations occur according to the way in which rings are bent, either of these rules works out very well in practice. They show, however, that bending an angle is very different from bending a ring of equal section. In such a ring we take the *mean* diameter, and then deduce the circumference. But note how that would lead into error in the case of a ring of

angle-iron. Taking the ring in Fig. 287, 18 in. + 3 in. × 3.14159 = 5 ft. $5\frac{7}{8}$ in. long, so that the ring would be about 4 in. too long. Theoretically, in a ring of equal section, the layers within the mean diameter are compressed, and the layers without the mean diameter are extended. Actually much depends upon the heat and the breadth of the ring, so that in wide heavy rings not thoroughly heated the tendency is for them to come out rather larger than the estimated size. In an external angle ring the mass of metal is greatest about the vertical flange, so that while the horizontal flange will bear much extension, the vertical flange, and the throat on the line *a-a*, will not bear much compression. It is the thickness on the line *a-a* which mainly determines the size of ring, because the greatest amount of metal is massed there. The rules above given are simply

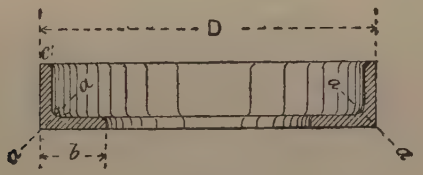


FIG. 288.

deductions from practice, in which the relation,—diam. × 3.14159 is modified to suit that practice. In each case the circumference corresponding with the length of bar taken comes in the thick metal of the throat of the angle.

For *interior* angles, Fig. 288, the rules are just the reverse of those given above, and the same reference figures are therefore used. Thus to take one rule only (1):—From the exterior diameter D, Fig. 288, *subtract* twice the diagonal thickness measured on the line *a-a*, and multiply the sum by 3.14159.

Although I have given approximate rules, they must be taken as approximate only. The section of an angle exercises an influence over the method of bending, that is, rings of different widths and thicknesses of flange will require to be cut to different lengths. In an angle with the flange external, the flange will be stretched, in one with the flange internal the flange will be contracted and squeezed. These effects will be more marked with increase in the section of the angle. Even

the quality of the material will also exercise an influence, as well as the heat, and mode of bending. Hence a workman has to make his own allowances suited to the angles upon which he is chiefly engaged, and for these reasons therefore the general rules which I have given must be taken as very close approximations only.

Tee-Iron Rings.—The rules for the lengths of exterior and interior rings of tee-iron, Figs. 289 and 290, are nearly the

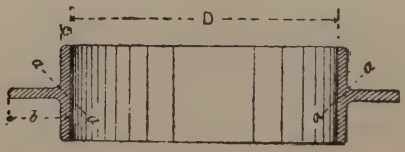


FIG. 289.

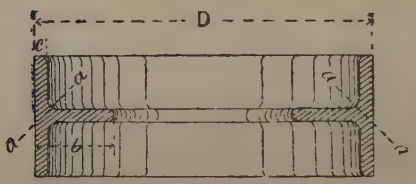


FIG. 290.

same as for exterior and interior angle-iron rings. But in practice, hoops made of tee-iron are always cut a little shorter than rings of the same size made in angle-iron.

Elliptical Rings.—Elliptical rings of angle-iron are treated as circles, the long and short diameters being added together, and divided by 2. Then, according as they are internal or external, the lengths are calculated precisely by the same methods as for internal or external circular rings.

Instead of using the number 3.14159, some workmen will use the rule which I gave for rings—namely, multiplying the effective diameter by 3, and adding $\frac{9}{16}$ in. to each foot of the product. Or they will multiply the diameter by 3, and add $\frac{1}{7}$th of the diameter to the product.

The trouble of calculating the length necessary for rings of angle and tee-iron can be avoided by using the tables of diameters and circumferences of circles given in engineers'

books of reference. Tables specially prepared for angle-iron rings may be misleading; but having a table of diameters and circumferences, the workman can modify the dimensions there given to suit the practice which has commended itself to his own experience and methods of work. Thus by rule (1), after adding twice the diagonal thickness on the line *a-a* to the inside diameter D, the result is the effective diameter, the circumference corresponding with which can be obtained from a table of diameters and circumferences.

Prices of Work per Ton.—The usual way to reckon the price of girder work is by weight. Knowing by calculation the number of tons weight in a job, it is priced at so much per ton. Some parts of the work will occupy more time than others; but taking one part with the other, the average labour will be covered by the price. The piecework price for single-plate girder work ranges from about 27s. to 35s. per ton, the former for plain parallel girders, the latter for fish-bellied girders, angle-brackets, &c. Box girders cost about 5s. per ton less than single-plate girders. Lattice girders cost from £2, 2s. 6d. to £2, 5s. a ton.

The piecework prices paid for work depend so much upon the appliances which exist in a shop that it is impossible to give any very fixed data. The use of special machinery makes so much difference. Thus in a very plain job, where the bulk of the work consists in riveting, the cost will be regulated in shops where hand riveting and machine riveting is done respectively by the difference in the cost of hand and machine riveting, the cutting of plates and angles to size being a relatively small item. But in marking out and working curved and angled forms, the time occupied bears a larger proportion to the time occupied in riveting. Then such matters as drilling *versus* punching, the standard of excellence or otherwise required by inspectors, &c., affect the price. Still the prices given above are fair averages for ordinary fairly equipped workshops.

For Riveting.—The following are the prices for putting in rivets by hand in ordinary simple work, as through two thicknesses of plate of moderate thickness:—$\frac{5}{8}$ in. rivets, 5s. 6d. per 100; $\frac{3}{4}$ in., 7s. 6d. per 100; $\frac{7}{8}$ in., 9s. 6d. per 100; 1 in., 11s. 6d. per 100. For hydraulic riveting, from 1s. 6d. to 2s.

For Flanging.—Flanging boiler crowns of about 3 ft. to 3 ft. 6 in. diameter by hand averages about 3s. 6d. each.

For Bending and Welding Angle-Irons.—For

bending and welding the corners of angle-iron frames the cost is from 1s. 3d. to 1s. 6d. per corner. So that a frame like Fig. 178, p. 167, will cost twice as much as a frame like Fig. 177 on the same page, because the former frame contains two separate welds at each corner, and the latter frame only one.

For Cross Tubes.—For welding and flanging cross tubes the price should be from 4s. to 4s. 6d. each, though from 7s. 6d. to 10s. is often paid for the largest sizes.

CHAPTER XV.

THE MARKING OUT OF WORK.

Mostly Marked to Full Size.—Reasons why Necessary.—Methods Employed.—Depends on Size of Work.—Geometrical Methods Required.—Errors in Rule Measurement.—Methods of Transferring Dimensions.—Development of Surfaces.—Telescopic Plates.—Curves of Large Radii.—Envelope of Conic Frustum.—Fitting of Cylindrical Parts.—Development of Envelopes of Spheres—Of Conical Water Tube—Drawing an Ellipse.

Mostly Marked to Full Size.—Nearly all work for plating and boiler-making is marked out to full size before being proceeded with. The exception is chiefly in the case of standard work, for which templets are kept. But as this constitutes but a small section of the work actually done in almost any shop, it follows that most jobs have to be marked out to full size. In some cases this is done directly upon the plates which have to be used. But this only applies to very plain and plated work. In built up braced work it is obviously impossible. Large drawing boards are therefore resorted to, or a large smooth floor area. The dimensions thus laid down are either transferred directly to the plates and bars which are to be used, or to templets which are laid upon the plates and bars.

Reasons why Necessary.—The necessity for marking work out to full size is one which applies very much to engineers' work in general,—the necessity for absolute accuracy which is unattainable by mere calculation however carefully done, the risk of error always being present. Moreover, the due relations of many parts can only be seen on marking out, and a man can always judge of his work better by a full-sized drawing of it than from a scaled drawing. Then further, the

scaled drawings themselves often contain errors which are not apparent until they become set out to full size. Drawings of some plated work are very intricate,—a mass of interlacing lines, full and dotted, which are perfectly bewildering in their apparent confusion, and these have to be all traced and thought out in slow detail, and many errors, some slight, others serious, are often discovered in such drawings, and many practical improvements which the draughtsman neglects are suggested by the boiler-maker. In many cases then it is necessary to mark out plated and boiler work to full size, in all it is safe.

Methods Employed.—Boiler-makers' and platers' work being drawn out upon drawing boards, or floors, or upon the plates themselves, the methods adopted for marking lines vary somewhat. Plates are prepared for lines and centres by being whitened, boards are prepared by being whitened or blackened. A board may be whitened with chalk, or painted white. It is blackened with paint. A piece of plate may be whitened with chalk, but the lines will remain more permanently if it is done with a thin solution of whitening in water, allowed to dry. Speaking generally, the blackened surface is most suitable for the largest drawings, and the whitened surface for small work.

Depends on Size of Work.—The manner of marking lines depends mainly upon the size of work. The lines on small drawings, and on whitened surfaces, are marked with a scriber point, or with a lead pencil. Those on large drawings, and on a blackened surface, are marked from a strained chalk line, when straight. When curved they are usually marked with a trammel, or a scriber point, and set in afterwards with chalk to render them more clearly visible. Very long straight lines cannot be marked so accurately from a straight-edge as from a chalk line. The latter must be fine and even, and well strained, and then the lines marked from it will be fine, clear, sharply defined, and true.

Geometrical Methods Required. — Lines whose angular relations to one another are required to be very accurate, should not be laid down as a rule by means of squares and protracter, but by geometrical methods. The exception would be in the case of small work in which the risk of error would be slight. In large work, the slightest error in laying down a line from square or protracter becomes magnified with the length of the line, and therefore it is necessary to use the rules of geometry, using large trammels for the purpose.

Errors in Rule Measurement.—Error in rule measurement is also magnified on long distances by the use of a two foot rule. In good boiler shops a standard rule of from 10 ft. to 15 ft. in length, with the first 12 in. only divided into sixteenths, is kept for shop use, and this alone should be used when marking off long distances. By using a common two foot rule, an error of $\frac{1}{4}$ in. or $\frac{3}{8}$ in. is easily made in a length of 16 ft. or 20 ft. Centres should not be marked with a rule, but with trammels, compasses, and dividers. On metal plates the centres should be set in with a centre punch. On wooden drawing boards they should be encircled with a ring of chalk, to indicate their position at a glance. Circles which have to be punched, drilled, or bored out, should be set in with centre pop marks on the metal plates. All rivet holes which have to be countersunk should be distinguished from the common rivet holes by the abbreviation *ctsk* or *csk*, else the common rivets will be inserted, and will have to be cut out subsequently, and the holes countersunk.

Methods of Transferring Dimensions.—After a job is drawn out to full size on a board or floor, there are two methods of transferring the lines, dimensions, and rivet holes so obtained to the work. One is to carry the dimensions from the board to the work with trammels, straight-edge, chalk line, compasses, and so forth, the other to make templets by the drawing, and to use the templets to mark the positions of lines, circles, and so on, directly upon the face of the work, without measurement. The former method is usually followed in the case of jobs done singly, the latter in the case of repetitive and standardised work. The templets used are either made of wood or of iron. Wooden templets possess the great disadvantage of liability to shrink and curve out of truth, but they are cheap. They answer very well for angles and plates, because they are then of no great width. Wooden templets for plates, if framed together of narrow strips, will stand pretty well. For standardised work constantly being repeated, iron templets must be employed. They are made of thin plate, ranging from $\frac{1}{8}$ in. to $\frac{1}{4}$ in. thick, and when of large area, all parts which are not required for actual use are cut out in order to lighten the weight for lifting about. Once made, these templets are indestructible.

Development of Surfaces.—To treat of the development of enveloping surfaces fully would occupy several chapters. I can only point out some of the leading principles involved in

such development, hoping to treat the subject exhaustively in a future volume.

Telescopic Plates.—To mark out the shape of a telescopic plate such as is required for the fire-box of a vertical boiler, or for the barrel of a locomotive, or an externally fired egg-ended boiler, the development is that of the frustum of a cone. But it is not customary to lay down the radial lines and curved edges with reference to the centre of the circle of which the frustum when unrolled, or developed, forms a sector. This would not be practicable nor necessary in many cases. Neither is it usual to obtain the length of the versed sine by calculation, though it is easy to do so. The most common practice is to lay down the lines thus :—Let Fig. 291 represent the frustum for which the development is required. Obtain the lengths of the circumferences of the smaller, and of the larger diameters A and B, and lay them down at the distance C apart, upon a plate two or three inches wider than C, Fig. 292, the taper of the edges *c-a*, *b-d* being made equal from the centre line, *x-x* ;—*a-b* then represents the circumference of the plate upon the small diameter, and *c-d* its circumference on the large diameter. Draw the lines *a-c*, *b-d*, and these will be the edges of the plate, to which must be added the necessary overlap (dotted) for the riveted seam. Now set a square to the edge *a-c*, and draw the line *c-e*, then set the square to the edge *b-d*, and draw the line *d-e*. Bisect *e-f* at *g*, and *g* will be the point through which the curve *c-g-d* will be drawn. The curve *a-h-b* will be drawn parallel with *c-g-d*. These curves will not be

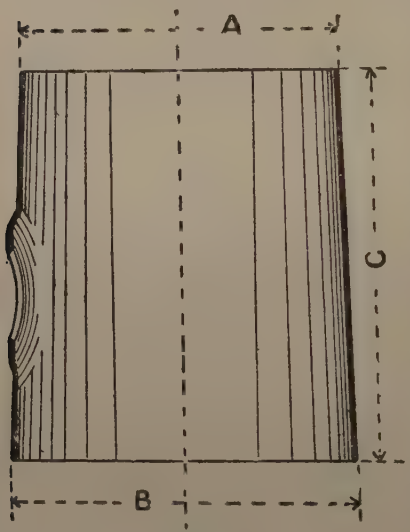


FIG. 291.

drawn with trammels, but by bending a strip of wood or metal evenly, so that it touches the three points of intersection of the curve, or by the intersection of lines (*see* Figs. 295, 296, p. 272). There are other methods, but these are the simplest.

Although I have given a very common, and the most usual shop method of marking out a plate for the frustum of a cone, suitable for a tapered fire-box, or a telescopic shell, I ought to say that it is not strictly accurate. It is true enough for most work, because the curvature is so slight, that a slight error is not apparent. A nearer approximation to truth can be obtained by keeping the point *g* in Fig. 292 a little nearer to *f* than to *e*, in the proportion of about 4 to 6, or 4 to 5; and this for all practical purposes would be quite accurate enough for boiler

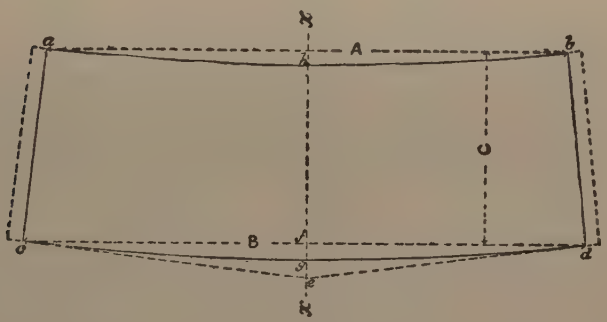


FIG. 292.

shop work. But in the case of conic frusta of considerable slant, it would not be true enough, and recourse would then have to be made to a trammel, or to calculation.

Curves of Large Radii.—I will therefore now describe how, without the aid of trammels, an absolutely correct curvature can be obtained for any conic frusta.

Let Fig. 293 represent one of the conic frustums of which a telescopic plated boiler consists, and let it consist of one plate in the circle, the breadth of the plate being 3 ft. 6 in., the diameter at the large end being 4 ft. 0 in., and the thickness *b* of the plate $\frac{3}{8}$ in. We shall first require to find the vertex F of the cone of which Fig. 293 represents one of the frusta. In order to bring this within the limits of the sketch, it is necessary to

exaggerate the taper of the cone in the diagram. The actual amount of coning in this case is equal to twice the thickness of the plate measured on the length of 42 in. In the fire-box of a vertical boiler it would be equal to from $2\frac{1}{2}$ in. to 4 in. The vertex may be found by the following proportion :—The thickness *b* : B G : : B A : B F, or in words :—As the thickness of the boiler plate is to the radius of the boiler, so is the breadth of the plate to the edge of the cone, and this, namely B-F, will be the radius with which the curve of the outside of the templet must be described.

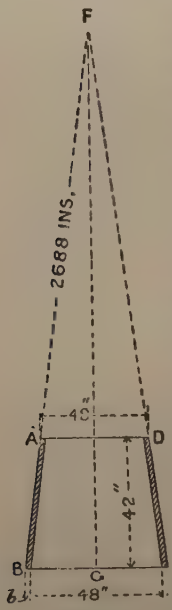


FIG. 293.

In this instance :—As $\frac{3}{8}$ in. : 24 in. : : 42 : edge of cone = 2,688 in. 2,688 inches therefore will = the radius required to give the requisite curve of the outside of templet.

We now require the length of each plate, both on the outer and inner curve lines. To the inside diameter of the boiler = 4 ft. 0 in., add the thickness of the plate $\frac{3}{8}$ in. = $48\frac{3}{8}$ in. This equals the diameter. Obtain the circumference by multiplying by $\frac{22}{7}$ = 152.0357 in. This gives the length of each plate on the outer curve. And as the diameter of the small end of the frustum is twice the thickness of the plate less than the larger, or $47\frac{1}{4}$ in., to which must be added the thickness of plate = $47\frac{5}{8}$ in., the circumference will therefore equal 149.678 inches. This will be the length of the plate on the inner curve line, and from these dimensions the templet may be constructed.

But with such radii as these, it would evidently be practically impossible to describe the desired circles by the ordinary method of trammels. The method commonly adopted is to calculate the versed sine, corresponding to the curve of the templet, and then obtain the curve by means of a bent lath, or by construction (*see* Fig. 296). The mode of calculating the versed sine is as follows :—By reference to Fig. 294, which represents the developed plate, with the amount of coning exaggerated, as in the previous figure, we see that F-B, B-G, G-F, form a right-angled triangle, of which two sides F-B, B-G have already been obtained. By Euclid, I. 47, we may obtain the

third G-F; subtracting this from H-F, which also is known, we get the versed sine G-H. Thus:—

$$\text{Versed sine } v = R - \sqrt{R^2 - (\tfrac{1}{2} C)^2}.$$

Or in words:—Square the radius R, from this subtract the square of half the chord C (which is the base of the triangle), and take the square root of the result. Then subtract this last quantity from the radius itself, and this gives the versed sine.

In this instance $v = 2688$ in. $- \sqrt{2688^2 - (76.017)^2} = 1.19$ in. 1.19 inches is therefore the height of the versed sine v.

I have reckoned that one plate only is used for the circle. If two plates are employed, then the versed sine is correspondingly less, and of course the error of the method shown in Fig. 292 would be very little. It would be practically nil if *g* is kept closer to *f* than to *e*, in the proportion named on p. 269.

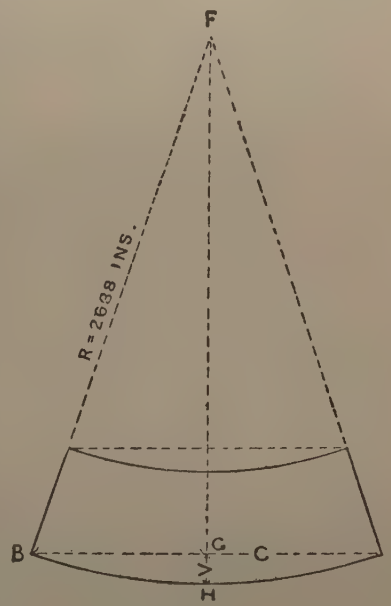


FIG. 294.

In reference to the drawing of curves of radii too large to be described with trammels, there are other methods in use besides that of bending a strip through points of intersection, which may not be sufficiently accurate in some cases in which the points of intersection are few, and the curves of considerable length. One good method is by employing an arrangement of straight-edges, Fig. 295, the other by means of intersecting lines, Fig. 296.

In Fig. 295, the length of the chord upon which the circle arc has to be drawn, is marked,—A-B, and the height of the versed sine at C. Lines are drawn, making the angles A, C, B. The straight-edges D, E are set to this angle, and united at C, and again by means of F. The length of each straight-edge

must be rather greater than the length A-B. Pins are stuck in at A and B, and a scriber held or fixed at C, and then when the templet triangle is moved round against the pins at A and B, the scriber will mark the curve which passes through A, C, B correctly. But in many jobs this method is not so convenient or practicable as a method of intersecting lines. The latter is

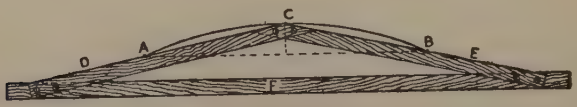


FIG. 295.

FIG. 296.

shown in Fig. 296, and is very frequently resorted to. In this figure, A, C, B are the three points through which the curve has to pass. Draw the chord A-B, and the line E F passing through C. The height G between these lines is the versed sine. From C as a centre with radius C-A describe circle arcs A-H, B-J. Divide A-H, B-J into any number of equal parts 1, 2, 3, 4, and divide C-H, C-J also into the same number of equal parts 1′, 2′, 3′, 4′. Draw straight lines from the points 1, 2, 3, 4, and also A and B to the centre C, and from C as a centre draw circle arcs through 1′, 2′, 3′, 4′, cutting these radial lines. The points of intersection of 1, 1′, 2, 2′, &c., will be the points through which the curve which passes through A, C, B will be drawn.

Envelope of Conic Frustum.—When the envelope of a conic frustum is required, the curves of which can be drawn with compasses, or with trammels, the method shown in Fig. 297 is adopted. Prolong the lines which form the sides of the frustum until they meet at the centre C. With radii C-A, C-B, draw curves as shown. On these curves measure the circumferences corresponding with the diameters *a* and *b* respectively, as *a′*, *b′*, at the termination of which draw the radial line *c-c′*. Then the sector B, A, *c c′*, will be the envelope of the conic frustum required.

Fitting of Cylindrical Parts. — When cylindrical branches have to be fitted on curved surfaces, the shapes of the abutting edges are obtained by means of certain lengths obtained on parallel lines, set out equidistantly. The general methods adopted are similar, whether the axes of the cylinders are central, or out of centre, or set at an angle. The general method of setting out the development of such work will be apparent from Fig. 298, which represents the development for

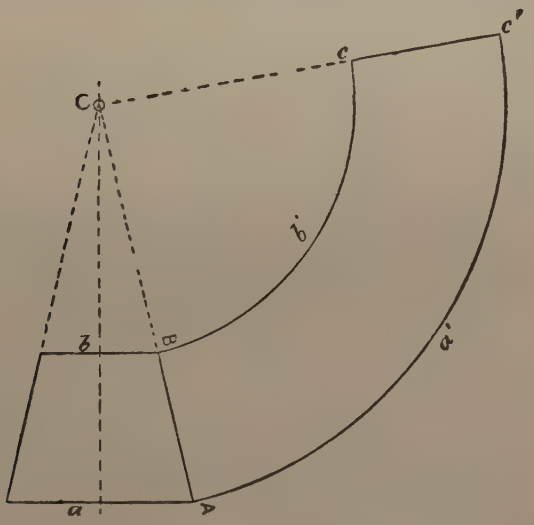


FIG. 297.

a steam dome, or similar branch piece, with its axis set centrally with that of the larger cylinder.

To obtain the development of the curved edge to fit the main cylinder, proceed thus :—

Draw a half plan of the dome, shown above, and divide the semi-circumference into any convenient number of equal parts, and carry these dimensions down to cut the main cylinder at A, C, B; 1, 2, 3, 4; *a*, *b*, *c*, *d*. A and B are of the same height, being on one semi-diameter; and there are two points on the other semi-diameter, at the height C. Set out a length D, equal to the circumference of the dome, divide this into four

equal quadrants A, A, C, C, B. Divide each of these quadrants into the same number of parts as the plan above, viz., 1, 2, 3, 4; *a*, *b*, *c*, *d*; and draw verticals corresponding therewith. On each of these verticals set off lengths from a horizontal line *e-f* representing the top edge of the dome, corresponding with the lengths of the vertical lines on the elevation of the dome, viz., 1, 2, 3, 4; *a*, *b*, *c*, *d*. A curve *g-h*, drawn through these lengths

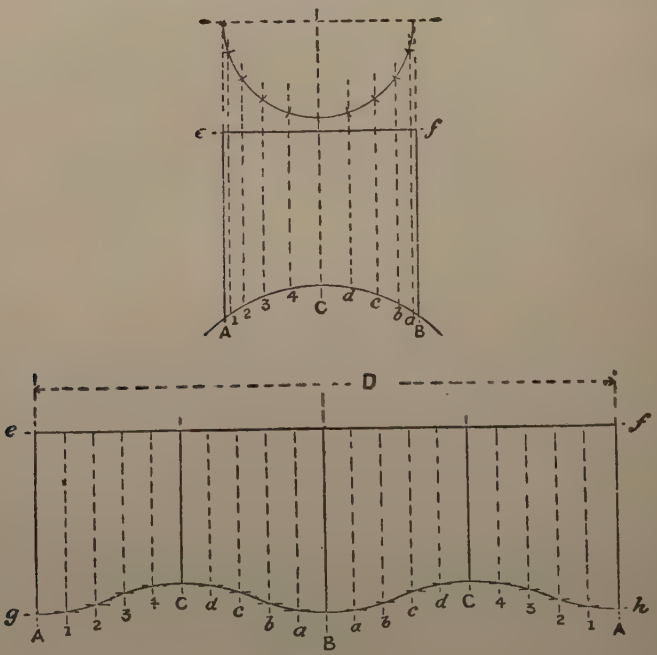


FIG. 298.

on the verticals of the unrolled plate, will give the curve required to fit the boiler barrel. The width necessary for the flange which rivets to the boiler must be added subsequently beyond the curved line *g-h*. Domes are usually welded up, but if riveted the width of overlap for riveting must be added at the ends.

This may be taken as typical of a very large class of work done in the boiler shop, in which the development of the edges of cylinders to fit other surfaces, cylindrical or otherwise, is obtained by the measurement of lengths taken on lines parallel and equidistant. The method is the same in principle whether the fitting occurs centrally, or to one side, or at an angle, or whether the cylinders are parallel, or tapered, or of equal or unequal sizes.

Figs. 299, 300 show branch pipes fitted to the sides of other vessels; in one case, Fig. 299, to a cylindrical vessel, in the

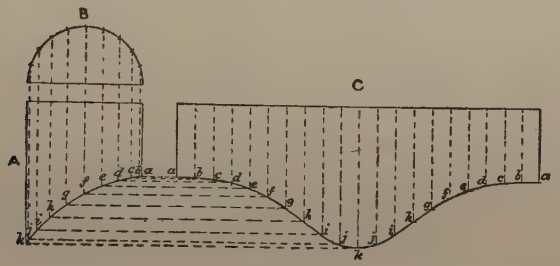


FIG. 299.

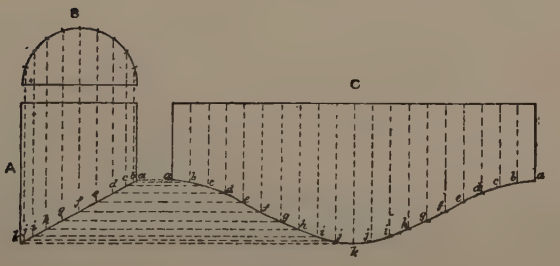


FIG. 300.

other, Fig. 300, to a bevelled face, or end. The methods of development are clear from the drawings, and from the foregoing description. In each case A is the pipe, cylinder, or dome. B is its half plan, C its developed plate. In each case the semi-circumference is divided out into any convenient number of equal parts *a*, *b*, *c*, *d*, *e*, *f*, *g*, *h*, *i*, *j*, *k*. Ordinates are carried down therefrom, cutting the fitting edges. Correspond

ing ordinates are drawn equidistantly in the length which represents the circumference, and the lengths for each ordinate are carried along. The curve drawn through the points so obtained is the curve required in each case.

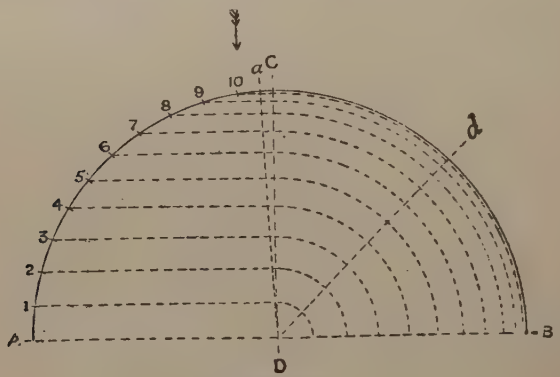


FIG. 301.

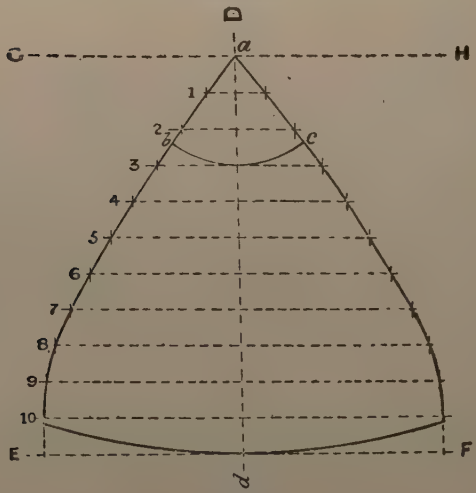


FIG 302.

Development of Envelopes of Spheres.—The development of plates for the envelopes of spheres is illustrated

in Figs. 301–304. Although the egg-ended boiler does not come into boiler-makers' practice so much as formerly, yet repairs to such are necessary in the Midlands. And plates forming portions of spherical surfaces are often required for vessels of various kinds, as pans, buoys, &c., so that Figs. 301, 304, have their applications in several jobs.

Plates to form the envelopes of spheres may have various forms.

In any case the dimensions and shapes are obtained by measurement of lengths on certain lines laid down in the development. By understanding the development of one plate, it is easy to understand that of others.

Fig. 301 shows a hemisphere in elevation, on its diameter line A-B. To obtain lines upon which lengths for development are to be set out, divide a quadrant A-C, into any number of equal parts, marked in the figure, 1 to 10. In Fig. 302 draw two parallel lines E-F, G-H, at a distance apart equal to the distance between A and C, measured round the quadrant, that is :—

$$\frac{A - - - B \times 3.14159}{4}$$

and divide the distance between these parallel lines by ten other lines, with the same compass set for the divisions 1-10 in Fig. 301. Thus the quadrant A-C in Fig. 301 is laid out flat in Fig. 302, with its lines of division 1-10 in readiness for the lengths by which the bounding curves of the plate are to be obtained. To obtain these, proceed as follows :—

On the right hand side of the centre line C-D draw arcs of circles from the centre D, the circle arcs being prolongations of the divisions 1-10 carried along in lines parallel with A-B. Obviously now these circle arcs correspond with a plan view of the quadrant A-C, viewed as shown by the arrow, and with the lines of division 1-10 carried round the surface of the quadrant parallel with the base A-B ; and the centre D will be the centre of the right hand quadrant corresponding with the centre C of the left hand quadrant. So that if we bisect the right hand quadrant C-B, at D-*d*, the centre line D-*d* will correspond with the centre line *d*-D in Fig. 302, and the lengths of circle arcs measured equidistantly from D-*d* on the lines of division 1-10 in Fig. 301, and marked equidistantly from D-*d* on the lines 1-10, Fig. 302, will give the widths of plate on those lines. The lengths of the circle arcs on each line of division can be obtained by

calculation as quadrants of their respective circles, but that is not the usual, nor the safer method. The safer way is to step round on each arc with dividers so many times. But by setting out a length for an arc as shown at *a*, Fig. 301, chord

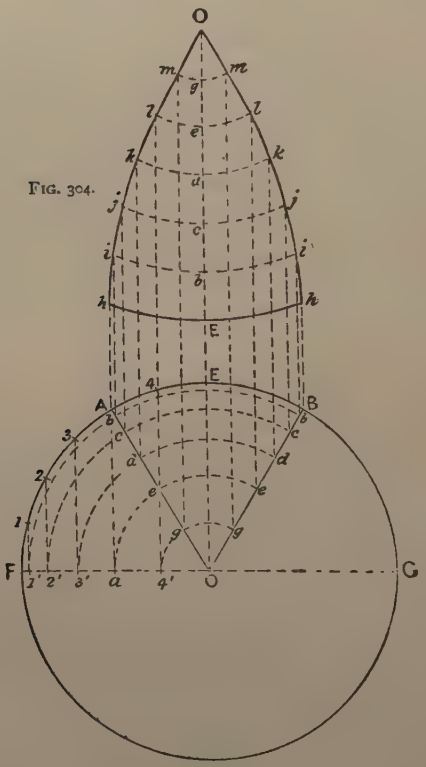


FIG. 304.

FIG. 303.

lines can be taken between D-*d* and *a*-D and transferred to Fig. 302 on each side of D-*d*. Through these points the curves required will be drawn.

The curve of the bottom edge of the plate is usually drawn with a radius equal to the distance between the lines E-F, G-H,

with centre set at the apex *a*, the distance between these lines being equal to the height of a cone, of which the Fig. 302 is a portion.

If the plate instead of being a quadrant of a circle is to form the sixth or any other segment of a circle, then the same general method will be adopted, only that the aliquot division of the circle will be different.

When the plates stop short of the centre, as in Fig. 302, *b-c*, the end being covered with a tippet plate, then the length required is measured round the curve, and the curve of the edge struck from the apex of the cone.

To mark a crown or end plate, no lines of division are required, but a circle is struck of radius equal to the length of arc required, and the plate will be right when hammered to curvature.

In all cases the width of overlap is added after the net dimensions of the plates are obtained.

Another way to mark out the plates for an egg-ended boiler, or for any hemispherical end, is shown in Figs. 303, 304. Let Fig. 303 be a plan view of the end of the boiler to be divided into the requisite number of plates—six in this case. A, B, O is one plate ; it extends to the centre O. But it may also stop short of the centre in order to allow of a central covering plate being used. E, O is the centre line of this plate, at right angles with the centre line F, G. Divide the quadrant F, E, into any convenient number of equal parts, in this case 1, 2, 3, A, 4. Carry lines from the points of division down to cut the centre line F, G, at 1′, 2′, 3′, *a*, 4′. From O as a centre draw circle arcs from 1′, 2′, 3′, *a*, 4′, cutting the plate A, B, O at *b*, *c*, *d*, *e*, *g* respectively.

Now in Fig. 304, on the centre line E, O,—equal in length to the quadrant E, O, in Fig. 303, that is measured round the quadrant E-F,—divide out certain widths *b*, *c*, *d*, *e*, *g*, corresponding with the divisions obtained in Fig. 303 below. From O, Fig. 304, as a centre, describe circle arcs where E, *b*, *c*, *d*, *e*, *g* cut the centre line E-O. To these lines project the lengths of the circle arcs of the segment of the circle A, B, O from Fig. 303 below. Through the points of intersection *h*, *i*, *j* *k*, *l*, *m*, the curves of the edges of the segmental plate will be drawn.

Geometrical rules for the development of the envelopes of curved bodies must be used with caution, because of the

uncertain effects of heating, and of working sheet metal. In such a material as paper, for example, the rules would not lead to error, but the case is different with metal, which is subject to contraction and to stretching under extremes of temperature, hammering, and squeezing. Much work of this kind has therefore to be done tentatively; a man has to feel his way cautiously,

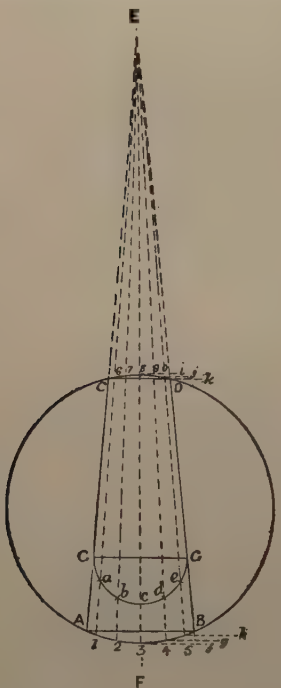


FIG. 305.

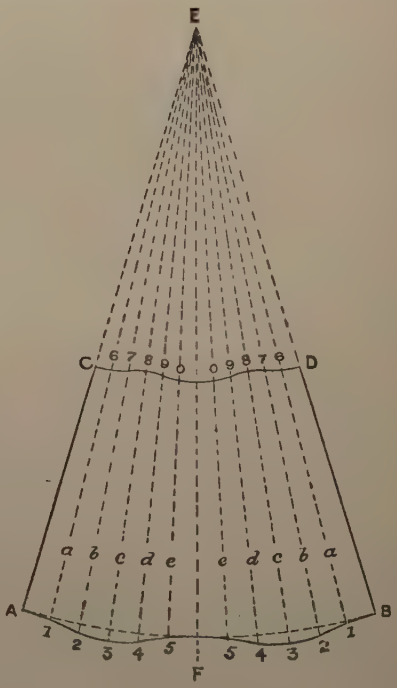


FIG. 306.

else he will run frequent risk of spoiling his plates. No general rule can be laid down. Thus in Figs. 302 and 304, the radii of the curved ends are given as being struck from the apex or centre of the plates. But in practice this radius should be greater,—by how much depends on the working of the plate. Shrinkage takes place down the edges of the plates, and the

radius must be increased to compensate for this. In practice the radius may be increased by one half, so lengthening the corners.

When there are several plates wanted all alike, one only should be cut at first, and that to slightly larger dimensions than the geometrical figure would give, and then bent to curvature, and tried on the drawing, and when practicable, in place. Rivet holes should not be made until after the dimensions of the plate are fixed. Then if the work is of a character likely to be repeated, a templet plate of thin sheet iron should be made and kept for permanent reference.

Development of Conical Water Tube.—The development of the plate for a conical water tube is shown in Figs. 305 and 306.

A, B, C, D, is the tube, of diameters A-B, C-D. The flue within which it fits is indicated by the circumscribed circle. Flanges are not shown. If they are employed, a suitable addition would be made to the edges of the developed plate. If not used, a very slight addition would be made for welding.

Project the lines A-C, B-D, to a centre E. Draw a line G-G anywhere, at right angles with the centre line E-F of the tube. Upon that, strike a half circle, and divide it into any number of equal parts G, *a*, *b*, *c*, *d*, *e*, G. Draw lines through the points of division to the centre E in one direction, and cutting the flue circle in the other direction at 1, 2, 3, 4, 5. The flue circle will also be cut at 6, 7, 8, 9, 0, at the small end of the tube. The intersections of these radial lines with the flue circle give the lengths for the development of the tube.

But the lengths cannot be measured directly upon any but the lines A, B, because of the tapering form intersecting the other lines. Their lengths therefore are projected to the line B, as indicated by the dotted horizontal lines *f*, *g*, *h*, on the large end; *i*, *j*, *k*, on the small end.

For the plate, Fig. 306, from a centre E, draw a curve A-B, with radius E-A, equal in length to the radius E-A in Fig. 305. Make the length of A-B equal to the circumference of the large end, A-B, of the tube in Fig. 305. Divide each half of this into the same number of equal parts, 1, 2, 3, 4, 5, as the semicircle G-G, *a*, *b*, *c*, *d*, *e*, in Fig. 305. On these lines of equal division, the dimensions will be transferred from Fig. 305. Thus for the large end :—For line E-3 take the projected length where *f* cuts E-B, and lay it down on lines 3, 3 in Fig. 306. Perform the

same operation for lines 2 and 4, and also for 1 and 5. For the small end, for line E-8 take the projected length where *i* cuts E-D, and lay it down on lines 8, 8 in Fig. 306. Perform the

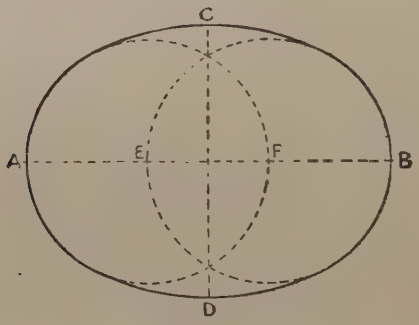


FIG. 307.

same operation for lines 7 and 9, and for 6 and 0, and also for C and D. Curves drawn through these points will give the development of the plate.

Drawing an Ellipse.—One method out of several of drawing an ellipse is shown in Fig. 307. Divide the conjugate axis A-B, into three equal parts A-E, E-F, F-B. From E and F, with radii E-A, F-B, strike circle arcs. Then find centres which will connect C and D with these circle arcs.

CHAPTER XVI.

THE ESTIMATION OF WEIGHTS, Etc.

Estimates for Cost of Work—Based on Weights.—Direct Method of Calculation of Weights—Calculations Based on Tables.—Weighing a Unit Piece, Unit Measurements, and Multipliers.—Cubic and Superficial Measurements.—The Geometrical Forms of Material.—How to Utilise Tables.—Useful Multipliers.—Relative Weights.—Estimation of Rivets.—Mensuration.—Of Plane Figures—Parallelograms.—The Use of Decimals.—Triangles.—Quadrilaterals.—Trapezoids.—Polygons.—Circles.—Circular Rings.—Sector.—Segment.—Enveloping Surfaces.—Of Cylinder.—Sphere.—Zone of Sphere.—Volumes.—Of Rectangular Body.—Parallelogram.—Cylinder.—Annular Vessel. Pyramid.—Cone.—Sphere.—Methods Adopted for Simplifying Calculations.—Averaging.

Estimates for Cost of Work—Based on Weights.—A foreman in a boiler shop often has to give estimates for cost of work. These estimates are most often based on a more or less approximate estimation of the *weight* of work, the price being given in at so much per ton—£1, £1, 5s., £1, 10s., &c., per ton. None too much time is usually available for these estimates, therefore rapid methods of calculation are desirable. In some cases, however, estimations of weights require to be made very exactly.

Direct Method of Calculation of Weights—Calculations Based on Tables.—There are various methods of calculation adopted. There is direct calculation, without the aid of tables of weights, and there is the calculation based on, or assisted by tables of weights. It is necessary to be able to do both. It would never do in a shop to waste time by calculating everything like a schoolboy. But the man who depends upon tables, and who cannot reckon anything without them, will often find himself in difficulty. Tables, however full, cannot cover everything that arises in practice, and no one book of tables embraces all even that is useful.

So that a man while knowing how to press tables into his service, should, when necessary, be independent of them.

Weighing a Unit Piece, Unit Measurements, and Multipliers.—The estimation of weights is never done in the boiler shop by the philosophical method of displacement of water. It is always done in one of two ways:—By direct weighing of a sample, this of course being only applicable in a few cases, or by mensuration, and the use of multipliers. The first method is applicable in such cases as this:—When estimating the weight of a quantity of rivets, to take one rivet of the correct size, weigh it, and multiply by the number required; and this is more accurate than any calculation. If a number of plates or bars of the same sizes are wanted, the same method is the best to adopt. But with these exceptions, the direct method is seldom applicable, but the weight must be obtained by measuring areas and solid contents, and multiplying the results by a suitable multiplier. Thus, the most common and useful multiplier is that by which cubic inches is converted into lbs. avoirdupois. Cubic inches being rectangular figures, are the easiest units of solidity to obtain by mensuration, and lbs. avoirdupois are the most convenient units of weight, from which the higher units, tons, cwts., qrs., can be obtained. The multiplier by which cubic inches of wrought-iron are converted into lbs. is .28, that by which cubic inches of steel is converted into lbs. is .283—steel being slightly heavier than iron.

Cubic and Superficial Measurements. — But in estimating weights, it is not always convenient to bring everything into cubic inches, but it is in very many cases easier to obtain superficial area, to consider the weight of a plate of that area, and of the thickness which a plate happens to be. Hence the tables in which the weight of one square foot of plate of a certain thickness is given are very valuable.

The Geometrical Forms of Material.—The majority of plates used in the boiler shop are of plain rectangular, or of circular form. But many also are "sketch plates," ordered as such, and many plates also are cut to irregular shapes in the shop. Many form envelopes of portions of cones and spheres, and in estimating the weight of all such plates the amount of their superficies has to be calculated by the rules of mensuration relating to triangles, polygons, conic frusta, zones, segments of spheres, &c. &c.; and then the solidity and weight estimated therefrom.

How to Utilise Tables.—In the estimation of the weights of round, square, and flat bar iron, the weights are generally obtained directly from tables, so that there is no need to go to the trouble of estimating the areas of the sections and the weights. As bars are generally used in long lengths, it is convenient to have the weights given per foot of length, a convenient unit, from which the lengths of several feet or of fractional parts of a foot can be deduced. In the case of section irons, such as angles and tees, it is not easy to give tables that can be considered in any sense complete, because of the immense diversity in the dimensions in which these sectional forms are made. Tables of some of the most usual sizes might be given, and would be useful. But in shops the general method used is to estimate the number of united inches in the cross section of an angle or tee, then obtain the weight of one inch in length with a multiplier, and thence the weight of any quantity. Or, having obtained the number of united inches in a given cross section, turn to a table of the weight of round, square, or flat bars, and look for a cross section which corresponds with that obtained. Then the table will give the weight of a foot in length of material having that cross section.

The weight of channels and joists, or **H** irons, is always given per foot run by the makers of these sections, so that there is never any need to calculate them.

Useful Multipliers.—There are a good few multipliers besides those for converting cubic inches into lbs.; some are used more frequently than others, some are approximate, some exact. I will tabulate some of them :—

Pounds × .009 = cwts.
,, × .00045 = tons.

Weight of round bars in lbs. avoirdupois :—Square the diameter in inches, multiply by the length in feet, and the product by 2.63 for iron, and by 2.67 for steel.

Weight of square bars in lbs. avoirdupois :—Multiply the area of the cross section in inches by the length in feet, and the product by 3.36 for iron, and by 3.4 for steel.

The thickness of a plate of wrought-iron, 12 in. × 12 in. × 1 in. thick, averages about 40 lbs.

Therefore the thickness of any plate given in inches and fractions of an inch × 40 = lbs. per square foot.

The thickness in eighths of an inch × .5 = lbs. per square

foot. The thickness in tenths of an inch × .4 = lbs. per square foot.

Numbers occasionally useful are the following :—

Square inches	×	.007	= square feet.
Circular "	×	.00546	= "
Cylindrical inches	×	.0004546	= cubic feet.
Cubic inches	×	.00058	= "
"	×	.003607	= imperial gallons.
Cubic feet	×	6.232	= "
Cylindrical inches	×	.002832	= "
Cylindrical feet	×	4.895	= "
Cubic inches	×	.281	= lbs. avoirdupois of wrought-iron.
"	×	.283	= steel.
"	×	.3225	= copper.
"	×	.3037	= brass.
"	×	.26	= zinc.
"	×	.4103	= lead.
"	×	.2636	= tin.
"	×	.4908	= mercury.
Cylindrical inches	×	.2168	= wrought-iron.
" "	×	.2223	= steel.
" "	×	.2533	= copper.
" "	×	.2385	= brass.
" "	×	.2042	= zinc.
" "	×	.3223	= lead.
" "	×	.207	= tin.
" "	×	.3854	= mercury.

Relative Weights.—Lastly, it is often desirable to be able to deduce the weight of a piece of work in one material from the weight of a piece of work in another material, as copper from wrought-iron, steel from cast-iron, and so on. The table of relative weights, p. 355, is most useful for this purpose, because the comparative weights of any of the materials there given can be seen at a glance, and it is only necessary to multiply the relative weight taken therefrom by the total weight of the piece of work in question to obtain the total result.

When getting out quantities for estimates, both exact and approximate methods of calculation are necessary. Thus, the greater the aggregate weights, the more exact must the calculations be, in order to avoid the risk of big error. If there are several hundreds of feet superficial required of a given thickness of plate, or several hundred feet of angle or tee section, or a large number of angle plate brackets, or bars, or rods of a given type, then the most exact methods attainable either by

mensuration or by direct weighing ought to be adopted. But when the quantity of a given type is small, then approximate methods of estimation are sufficient.

Estimation of Rivets.—A boiler-maker's estimate of the cost of a job is based to a very considerable extent upon the number of rivets in it, involving cost of pitching out, punching, or drilling, rymering, or countersinking, and closing up by hand, or by machine.

To estimate the number of rivets, often numbering several thousands in a job, is not so easy as it may seem to an unpractised man. One is apt to omit many details in a general drawing when time presses, and so under-estimate. The table, p. 353, is introduced for the purpose of facilitating such calculations. Having the number of feet run to be riveted up, and knowing the pitch and diameter of the rivets, the results are given in the table in multiples of ten, from which any number can be deduced. The best way to obtain the weight of rivets is to weigh one, and multiply that by the number required of the same dimension. If no rivet happens to be available, then the weight must be calculated from a table of the weight of round rods, making allowance for the extra weight of the head.

Mensuration.—A knowledge of mensuration and of the simpler problems in geometry is required in the boiler shop. The first finds its application in the getting out of areas, and volumes, or solidities required, both for the purpose of estimating weights and quantities, and for capacities of vessels of various kinds, the second for the drawing and development of work in general. A very brief and concise notice must be given to these.

Mensuration includes the measurement of—

I. The areas of plane or flat surfaces.

II. The areas of enveloping surfaces, that is the surfaces, flat or curved, which enclose hollow or solid bodies.

III. The volumes of solid contents of bodies, included within their enveloping surfaces, and capacities of hollow bodies or vessels.

Mensuration of Plane Figures—Parallelograms.—(I.) Plane rectangular or right-angled figures may be square or oblong, the first having all sides parallel, and its opposite of equal length, the second having its opposite sides parallel, and two of equal length. Both are termed parallelograms. There is

another parallelogram called a rhombus, in which the angles are not right angles, but in which the sides are parallel, and of equal length. In each of these figures the rule for finding the area is:—Multiply the length by the breadth. Or, as it is often put; multiply the base by the height,—any one side of either of these figures being termed the base, and then the perpendicular from that line is called the height. Hence to obtain the superficial area of a piece of plate of length 7 ft. 0 in., and of width 4 ft. 0 in. If in feet, $7 \times 4 = 28$ feet. If in inches, $84 \times 48 = 4032$ inches.

The Use of Decimals.—If the dimensions include inches, and fractions of inches, then it is easier to turn the dimensions into inches and decimal fractions of an inch before multiplying by the use of Table XXIX. in Appendix. So also if the dimensions are required in feet only, odd inches can be turned into decimals of a foot by the use of Table XXX. I need not give illustrative examples of matters so simple. But, obviously, care must be taken in all calculations not to mix up figures of different denominators, but feet must always be multiplied by feet, and inches by inches, and the product of feet must be feet, and that of inches must be inches. And the results will be *square* feet or *square* inches, and not feet square or inches square. Moreover, if we have a plate of a given area and length, we can find the breadth by dividing area by length, and so too from area and breadth we can calculate length. Further, knowing the area of a rectangle, the length of one of its sides can be obtained by extracting the square root of the area.

Triangles.—Of a triangle, it is easily determinable that its area is equal to that of one-half a rectangle, having the same base and height. Hence the rule to find the area of a triangle: —Multiply the length of the base into half the height. Or multiply together the base into the height, and take half the product. Also it follows that if we know the area of a triangle, and one dimension, either the base or the height, the other dimension can be found by dividing *twice* the area by the height or base, whichever we may happen to know, and the product will be the unknown dimension.

When the dimensions are given in terms of the length of the three sides, then the area is found as follows:—From half the *sum* of the three sides, subtract each side separately. Multiply the half sum and the three remainders together, the square root of the product will be the area.

Quadrilaterals.—A quadrilateral, Fig. 308, is a rectilineal figure with four sides, as a triangle is a rectilineal figure with three sides. The area of a quadrilateral is obtained by dividing it up into two triangles, having the diagonal for a base line, and

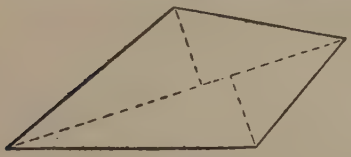


FIG. 308.

FIG. 309.

obtaining the area of each separately, their sum will be the area of the quadrilateral. Or, obviously, by an extension of the rule already given for triangles:—Multiply the sum of the perpendiculars by the diagonal, and take half the product.

Trapezoids.—A trapezoid, Fig. 309, is a rectilineal figure which has two sides only parallel. Its area is obtained thus:—Multiply the sum of the two parallel sides by the perpendicular distance between them, and half the product will be the area.

Polygons.—Lastly, the area of any rectilineal polygonal figure, Fig. 310, is obtained by dividing it up into figures of any form convenient for measurement, as triangles, and trapezoids, calculating the areas of each figure separately by the methods already given, and then adding their various sums together, the total of which will be the area of the polygonal figure.

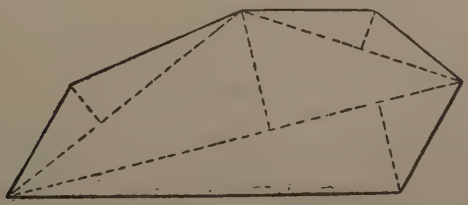


FIG. 310.

Circles.—The area of a circle is found by either of the following rules:—

Square the diameter, and multiply the product by .7854.

Square the radius, and multiply the product by 3.14159.

And conversely, having the area of a circle given, to find the diameter or the radius :—

Divide the area by .7854, and extract the square root of the quotient for the diameter.

Divide the area by 3.14159, and extract the square root of the quotient for the radius.

Circular Rings.—The area of a circular ring is found thus :—Find the area of a circle corresponding with the inner diameter of the ring, and the area of a circle corresponding with the outer diameter of the ring. Subtract the area of the inner circle from the area of the outer circle, and the remainder will be the area of the circular ring.

Sectors.—A sector of a circle, Fig. 311, is a figure bounded by two radii, and the arc included between them. To find the

FIG. 311.

FIG. 312.

area of a sector :—As 360 is to the number of degrees in the angle made by the radii of the sector, so is the area of the complete circle to the area of the sector.

Segment.—A segment of a circle, Fig. 312, is a figure bounded by a chord, and the arc which it cuts off. Any chord which is not a diameter, cuts a circle into a greater and a lesser segment. The rule for finding the area of a segment is usually given for the area of the lesser segment of the two, because if the area of the larger segment is required, it can be obtained by subtracting the area of the smaller from the area of the complete circle.

The rule for finding the area of a segment which is less than a semicircle is :—

Find the area, Fig. 313, of the sector A, B, C, D, which has

the same arc, and then subtract from it the area of the triangle A, B, D, included between the radii of the sector, and the chord of the segment.

Enveloping Surfaces.—(II.) The areas of the surfaces which envelop hollow or solid bodies can obviously be calculated in many cases from the rules already given for plane or flat surfaces. This would apply in the cases of rectangular shaped vessels, pyramidal wedge-shaped vessels, cylinders, circular cones, zones of spheres, &c. I need only note two or three examples.

Cylinder.—The area of the surfaces of a cylinder is obtained by adding together the areas of the two ends and that of the curved surface. The area of the latter is equal to the

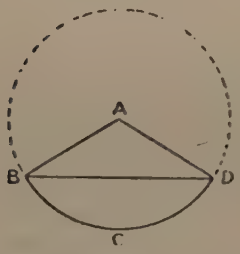


FIG. 313.

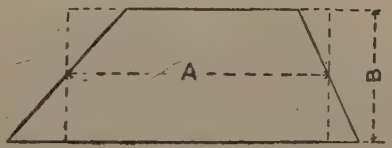


FIG. 314.

circumference, = diam. × 3.14159 × height or distance between ends. The areas of the surfaces of vessels which form segments of a cylinder can be calculated by rules already given.

Sphere.—To obtain the area of the surface of a sphere:—Square the diameter, and multiply the product by 3.14159.

Zone of Sphere.—The area of the curved surface of a zone of a sphere, or of a segment of a sphere, is found by the rule:—Multiply the circumference of the sphere by the breadth or height of the zone or sphere.

Volumes.—(III.) To find the volumes, or the solid contents of bodies included between their enveloping sides, several of the foregoing rules find application.

Rectangular Body.—Thus to find the volume containing in a solid rectangular body, the length is multiplied into the breadth, and then the product, which is the area, is multiplied into the height. And this expresses in a very general

way the method of obtaining the cubical contents of bodies bounded by plane faces. Hence the meaning of the term "cube," which signifies the multiplication of a number by itself, and the product by the number again.

Parallelogram—Cylinder.—Similarly, the volumes of a parallelogram, or of a cylinder, will be obtained by multiplying the area of the end, or base, into the height.

Segment of Cylinder.—The contents of a vessel having the form in plan of a segment of a cylinder, can be obtained by multiplying the area of the segment into the height of the vessel.

Annular Vessel.—The contents of an annular, or ring-shaped vessel, is found by multiplying the area of the ring, by the method already given, into the depth.

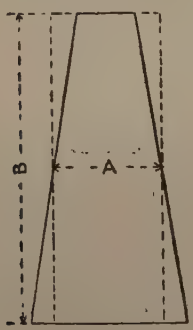


FIG. 315.

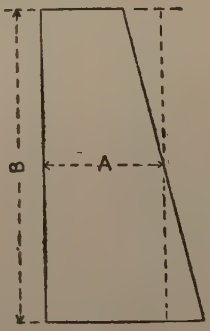


FIG. 316.

Pyramid—Cone.—The volume of a pyramid, or of a cone, is obtained by multiplying the area of the base into the height, one-third of the product of which will be the area.

Sphere.—The volume of a sphere is obtained by multiplying the cube of the diameter by .5236.

Methods Adopted for Simplifying Calculations—Averaging.—These are only the principal rules which are required in the boiler shop. To treat the mensuration of the shop with fulness would require several chapters. For purposes of rough and ready calculation, rules of mensuration that involve many figures are not usually resorted to in the boiler shop, but methods of rough averaging of the simplest kind are employed. Thus, taking the quadrilateral figure, Fig. 308, a workman

would not divide it into two triangles in the orthodox fashion, and reckon out the area of the two triangles, and add them together. He would probably average a rectangle of the figure, by which the calculation would be slightly simplified. So with the trapezoid, Fig. 314, the mean length A multiplied by the width B would give the area. In the case of plates also, like Figs. 315, 316, the mean width A would be taken, and the length B, and the plates would be converted at once for purposes of calculation into plain rectangles, as shown by the dotted lines. A piece of plate like Fig. 317 would be divided into two portions, the lower part giving one rectangle, the upper being averaged as another, of mean length A, and

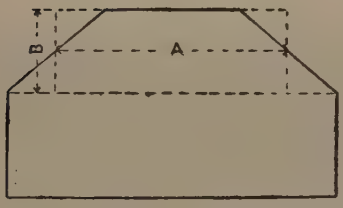


Fig. 317.

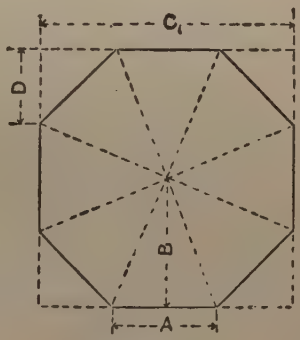


Fig. 318.

width B. In estimating too the area of the sector of a circle, Fig. 311, instead of making a rule-of-three sum, the area of a complete circle would be taken from a table of areas, and divided by the number of times the given sector would be contained in the circle. Similar methods would be adopted in the case of other figures.

The areas of regular polygons are obtained properly by dividing them into equal triangles. Thus the octagonal figure in Fig. 318 would contain eight triangles, shown dotted. The area of one triangle would be obtained by multiplying the length of its base A, by the perpendicular height B, and taking half the product, and that multiplied by 8 would give the area of the figure. In some cases it would be easier to take the area of a square figure of length and width C, and deduct from

it two smaller squares of length and width D. In Fig. 319 the area of the hexagonal figure can be obtained by dividing it into triangles. But a circle could be drawn as shown, averaging

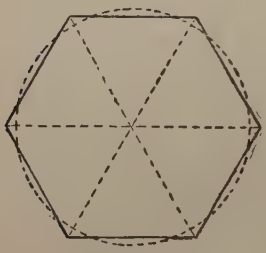


FIG. 319.

FIG. 320.

the flat sides, and the area of that taken from a table. In the decagon, Fig. 320, the coincidence of the circle and the polygonal sides is so near as to be practically exact.

Simpson's rule would seldom be employed in a boiler shop. Take, say, a fish-bellied girder, of which the superficial area should be required for the estimation of the weight. The method which would generally be used would be that indicated in Fig. 321. The girder would be divided into short sections A, by ordinates, the number of sections being greater or less according to the degree of accuracy required. The middle

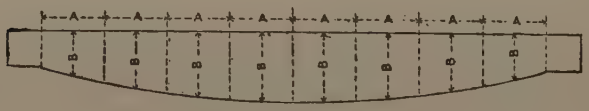


FIG. 321.

width B of each section is taken and multiplied into its length, and the totals of all the sections are added together. In a short section the curvature is practically nothing, not amounting perhaps to $\frac{1}{8}$th of an inch, so that the sections are practically rectangles.

By these and similar methods time is saved, and since most work is done against time, slight economies tell up.

CHAPTER XVII.

MACHINES.

Increase in Capacity and Weight.—Plate-Edge Planing Machines.—Bending Rolls.—Flattening Rolls.—Punching and Shearing Machines—Methods of Operation.—Light and Heavy Machines.—Horizontal Machines.——Combined Machines.—Multiple Punching Machines.—Drilling Machines—Various Kinds.—Boiler Shell Drilling Machines.—Boiler Flue Drilling Machines.—Portable Drilling Machines.—Countersinking.—Flanging Machines.—Angle-Iron Bevelling Machine.—Riveting Machines.—Electric Riveting.—Pneumatic Chipping and Caulking.—Rivet Furnaces.—Cold-Iron Saws.—Welding Hammers.

Increase in Capacity and Weight.—I have alluded very briefly to a few of the machines used in plating and boiler-making. But in order not to draw the attention too much from the details of workshop operations, I have omitted any extended reference to the numerous types of machines used for the various classes of work done in different shops. I cannot attempt to describe minute details of construction, but will point out the main features only of each type.

Boiler-makers' machine tools have been increasing in capacity and weight since the early period of their employment. About $\frac{3}{8}$ in. thickness was the limit of iron plates some thirty or forty years ago, and the machines of that time were made only to deal with plates of that thickness. Few punching and shearing machines of that period could punch or shear more than $\frac{1}{2}$ in. plate, and the depth of their gullets would not be more than from 12 in. to 15 in. The rolls were similarly small, weak, and narrow, adapted only for such thin plates. As the scantlings of boiler, girder, and ship plates were increased, there arose the demand for more capacious machines. The manufacturers fell into the easy error of bad proportioning, with the result that machines sprung or broke under the heavy duty required of

them. Gradually the lessons of failure have borne good fruit, and the result is now that the modern boiler shop is splendidly equipped with machine tools, being as well off in this respect as the general engineer's machine shop. It is impossible to describe all, or nearly all, these tools; but some of the principal of them at least call for a passing notice.

Plate-Edge Planing Machine.—The plate-edge planing machine (*see* pp. 76, 77) is one of the most common machine tools in the modern boiler shop. These are made to plane from about 4 ft. in length up to 30 ft. or more. No work at all should ever be put together with rough shorn edges. Planed edges render the plates sounder, less liable to crack, better fitting, and joints can be made and caulking can be done more easily and better. Yet, a few years ago, planing was exceptional practice.

A plate-edge planing machine has a very different appearance from the planing machine of the machinist. In the latter the work travels, and the tool remains stationary; in the former the work is clamped down upon the bed of the machine, and the tool travels from end to end on planed ways alongside. The tool saddle is operated by a large square-threaded screw, and is either reversible, cutting in both directions, or the saddle is provided with a quick-return movement. Some machines have a cross slide at one end for planing the ends of plates simultaneously. A plate-edge planing machine of 12 ft. or 14 ft. was considered a big machine a few years ago. Now such machines are made of 30 ft. or 35 ft.

The most modern type of plate planing machine is that in which two adjacent edges of a plate, or an edge and a butt, are planed simultaneously. There are two beds at right angles, each with its top beam, and with its tool-box and screw. The tool boxes are reversible, so permitting of cutting both in the forward and backward movement. A platform is suspended from each tool-carriage, so that the workman can travel with the tool. Several firms now manufacture these.

Messrs Thomas Shanks & Co. have made a massive machine, shown in Fig. 322, capable of planing up to 32 ft. at a stretch. It is fitted with overhang beam, so that any length of plate may be passed through. The beam is of cast-iron, and carries the clamping screws. Hydraulic rams are sometimes added in place of every third screw, for rapid clamping. The saddle is driven by a large square-threaded screw, operated

Fig. 323.

by the belt pulleys at the end, the saddle shifting the belts automatically through the medium of the striking rod at the front. The attendant stands on the platform of the saddle and reverses the tool-box at the end of each stroke, putting on the cut at the same time.

The edges of angle-irons are usually planed in the best classes of work, in order to facilitate caulking. This is generally done in the case of straight bars on the plate-edge planing machine. A special machine is, however, manufactured for the purpose by Messrs Scriven & Co., of Leeds. The angles are fed through the machine between upper and lower pairs of rolls, driven by belt and worm gear, the two edges of the bar being cut in transit by two cutting tools, adjustable by means of hand-wheels.

Bending Rolls.—When describing the bending of plates, p. 103, I alluded to the unsatisfactory action of bending rolls. One such feature was the impossibility of bending a plate up to the very edge; and this is just the portion where the curvature ought to be perfect, in order to form a close riveted joint. In plates for boilers of no great size, the usual practice is to form the terminal curvature by hammering the edge over upon one of the lower rolls, or over a templet block. In thick plates this is not practicable. There are bending rolls in which a plate can be bent to the very termination of the curve at one end, and then by reversing the plate in the rolls, the other end can be bent. In this machine the top roll is set vertically over one of the bottom ones, and the third roll—the adjustable one—is at the side. A useful addition to the ordinary heavy rolls is made in one of the machines of Messrs Rushworth, of Sowerby Bridge. It comprises an additional small, short roll provided under the ordinary rolls, its special function being the bending of small tubes which would otherwise have to be bent in a separate machine. The extra roll is 7 in. diameter by 5 ft. long. Horizontal rolls will range from about 4 ft. to 17 ft. in length.

For the heaviest work very special bending rolls are designed. In a huge machine made for the Fairfield Works, the rolls are kept of moderate diameter, which is always desirable; but to prevent them from springing, they are kept to their work by small friction rollers beneath the lower rolls and above the top roll. A light crane is pivoted at each end of the machine to carry the plates.

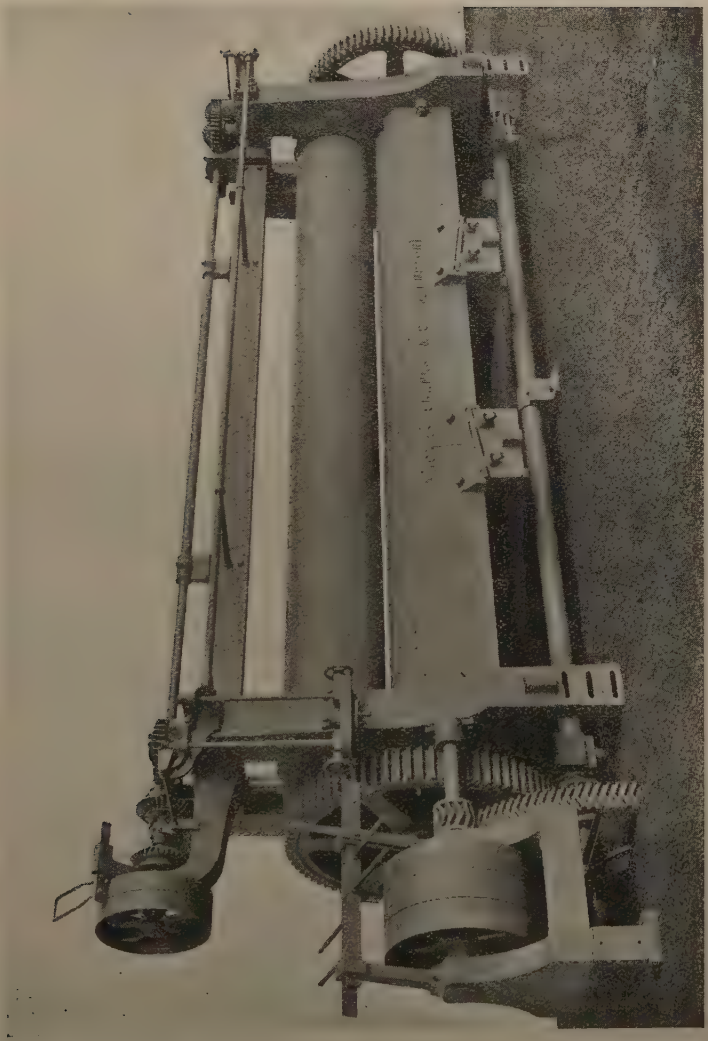


Fig 322.

Some of the horizontal rolls are of enormous capacity. Messrs Shanks & Co. construct them to take plates up to 36 ft. in width, the rolls being made of forged steel, instead of cast-iron, and the bottom ones are supported in gun-metal bearings at two points between the main bearings. These intermediate bearings lie in a girder below, and are adjusted by screws from the front. (*See* Fig. 323.) The rolls are 16½ in. diameter, and plates up to 2 in. thick can be dealt with. Double gearing

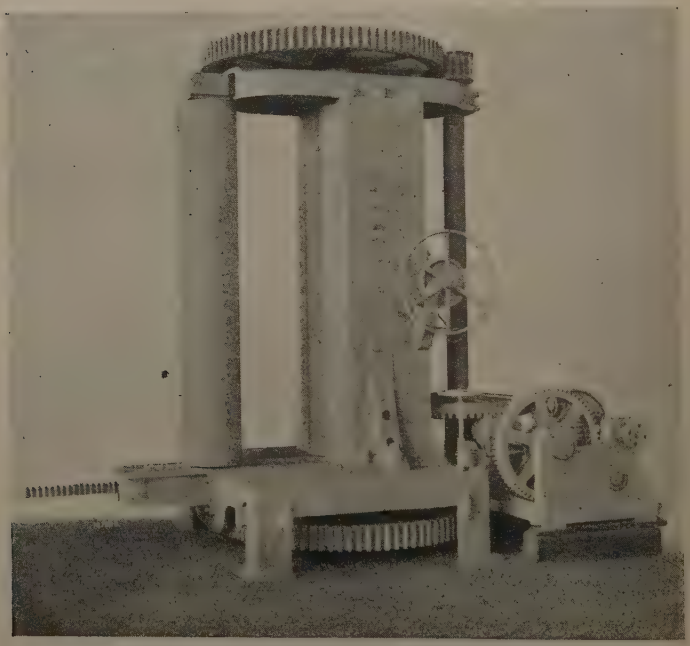


Fig. 324.

drives the two lower rolls from the belt pulleys, and other separate pulleys operate the raising screws for the top roll, through a clutch and reversing bevel gears.

Vertical plate-bending rolls are illustrated in Fig. 324. The introduction of rolls of this type must be credited to Messrs Palmer's shipbuilding works at Jarrow-on-Tyne. Being

manufacturers of marine boilers, the question of welds *versus* specially long plates came up for consideration. The difficulty of supporting long, heavy plates in horizontal rolls (as noted on page 100), suggested to a Mr Gibbs the employment of vertical rolls. But for these it is safe to say that the construction of the modern marine boiler with so few seams would be impracticable. Fig. 324 illustrates a large set of vertical rolls, by Messrs Thomas Shanks & Co., designed for plates up to 12½ ft. wide by 1¾ in. thick. A two-cylinder reversing engine is coupled to the flanged end of the shaft seen to the extreme right, and double purchase gearing connects up to the two

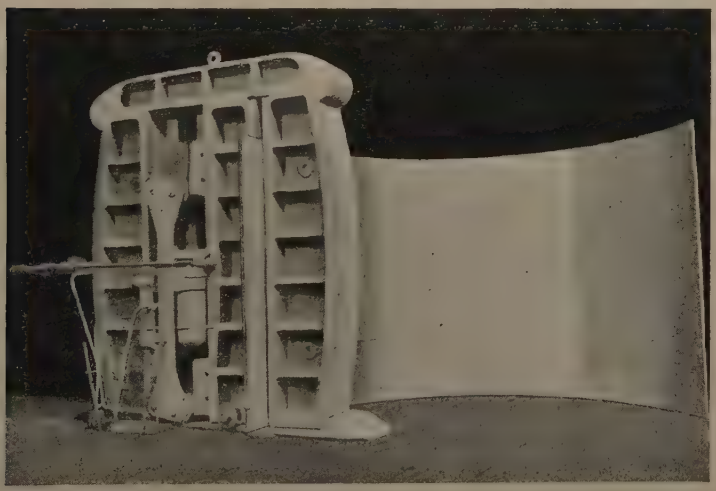


Fig. 325.

driving rolls, supported in the upright framing. Reversal is effected by the link motion of the reversing engine. The front roll is fitted so that it can be drawn out clear of its bearing at the top, leaving the space free to draw off a complete cylinder after it has been rolled. The rolls are of forged steel.

The hydraulic plate-bending machines possess some advantages over rolls; very short portions, such as straps, can be curved, and plates can be bent truly right up to the edge. The floor space occupied is also less than that

taken up by rolls. In Messrs Fielding & Platt's machine (Fig. 325) there are three portions, comprising the frame, the outer one on one side being curved on the inside face to take the plate, which is forced against it by a movable girder, also with its face curved. This girder is forced along by the combination of a hydraulic cylinder and ram with coupling rods, which carry rollers bearing against inclined planes on the girder, so that as the rollers rise with the ram they push the girder against the plate. When complete circles have to be produced, the outside beam is coupled to the outer part of the frame with a hinged bolt at the top, so that it can be swung out of the way when lifting the cylinder off. Automatic feeding gear is also fitted, when desired, comprising a small rope-drum which is given partial turns at each stroke of the machine, so pulling the plate along on its floor rollers; movements of about 3 in. at a time are imparted.

Flattening Rolls.—Some very large flattening rolls are made by Messrs Craig & Donald. Machines with five rollers are constructed to take plates up to 11 ft. wide by $1\frac{1}{2}$ in. thick, working them cold. The centre top roller is 28 in. diameter, the others 22 in. diameter. This firm has also developed a new form of mangle having only four rollers; one of the top ones is smaller than the rest, and it is moved up out of the way while a plate is passed through the three and given a slight curvature to take out the buckles, &c., and turned over and sent through again. Then the roll is brought down to the proper distance and the plate flattened by a pass. Electric driving is adopted for this class of machine, and the motor is fitted with a magnetic flapper brake, which grips the shaft immediately the current is shut off, so that a plate can be rolled right to its edge, and then stopped safely. A tramway type of controller is used for the driving and reversing, the motor being of reversible type.

In the patent straightening or flattening machine of Messrs Scriven & Co., there are two special features of importance. One is that the lower course of rollers, and not the upper, is adjustable, so that the weight of the rollers takes up any slack that may occur in the adjusting rolls and gear, none, therefore, remaining to be taken up when the plate enters the rolls. The gear for the adjustment is also thereby kept underneath the rollers, out of the way of the plates as they are being manipulated. The second feature is that the two outer rolls of the upper series are made removable, leaving the middle upper roll

only in place, so that the machine can be used as a plate-bending machine. By removing a loose cheek, circles can be drawn off the end of the roller after having been bent.

Punching and Shearing Machines — Methods of Operation.—Punching and shearing machines (*see* p. 71) are operated in three ways: either by means of an eccentric on the driving shaft, or by means of a cam and lever movement in combination, or by hydraulic power. The first imparts a direct vertical movement to the punch and the shears, because the movement of the eccentric operates the slide of the punch or of the shears directly. In the second the reciprocations of the slides are produced by long levers of approximately triangular outline, the flat under faces at the long end being moved up and down by cams on a central shaft, while the short ends are connected to the slides. At the shear blade end the lever fits by a rounded end in a recess in the slide, and so rocks it up and down, while at the punch end a coupling link ties the lever and slide together, provision being included for slipping the link laterally so that it does not drive until a lever is moved when the operator desires to punch. When an angle shear is incorporated in the machine, the slide of this is reciprocated up and down by a connecting rod worked from an eccentric on the same shaft that drives the levers. In the hydraulic system the movement is absolutely vertical, the slides being operated directly by the water pressure.

Up to the present time the first type has been in greatest favour, being used in the majority of ship, and girder, and boiler yards. The third type is largely in use, and very massive machines are made, especially for shearing wide plates.

The two forms of punching and shearing machines—the "eccentric," and the "lever," or "cam"—each possesses some advantage over the other. An eccentric machine was shown at Fig. 80, p. 71, a lever machine is shown at Fig. 326. In the eccentric, so called because the slide is operated by means of an eccentric upon the end of the main, or driving shaft, the slide has the same rate of travel during the return as during the cutting stroke. In the lever machine the return stroke is made at a quicker rate, and the rate will vary according to the shapes given to the opposite faces of the cam. In punching machines this is an obvious advantage, in shearing machines none.

To a certain extent time may be saved in an eccentric machine by increasing the length of the stroke of the punch, to

give the workman time to set the work, and running the machine at a higher speed. But this can only be done within a limited range, because the relative diameters of the driving shaft, and of the eccentric pin on the end, cannot be altered much without making the shaft too large, or the pin too small.

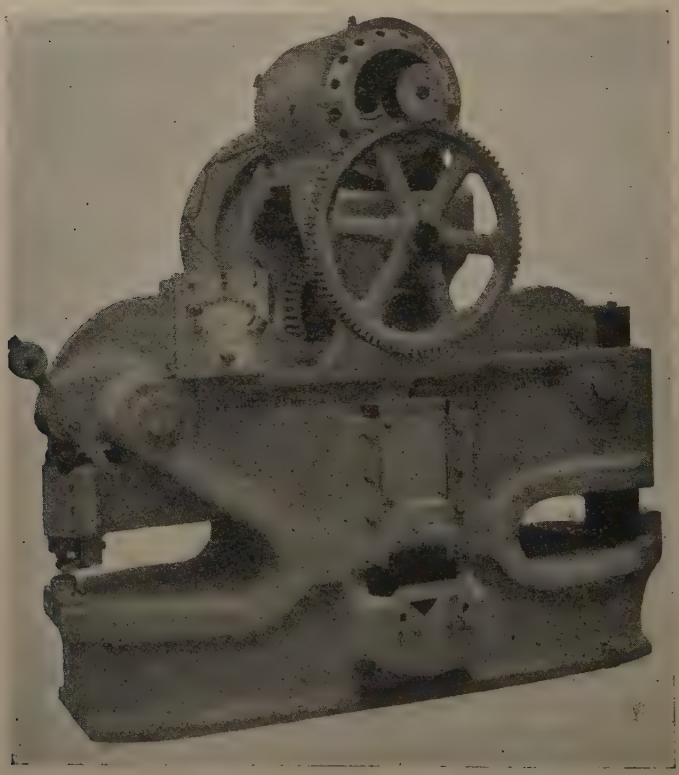


Fig. 326.

With a shearing machine the eccentric is better than the lever, because the shearing action is more gradual and prolonged than the punching, while the friction and strain is less, and the power required to drive correspondingly less.

In some lever machines the slide for punching is operated by means of a cam, while that for shearing receives its motion from an eccentric.

Fig. 326 is arranged for punching and shearing at opposite ends, and for angle shearing at the centre. An electric motor at the top of the frame drives by a raw-hide pinion to a spur gear on a shaft which is fitted with a heavy fly-wheel, and this shaft in turn rotates the cam shaft through other spur wheels. A stop motion is provided for the punch slide, and for the angle slide, while it may be noted that there is a cross-bar in front of the latter, to resist the upward thrust of angles while being shorn.

Light and Heavy Machines.—Punching and shearing machines are usually single geared up to a capacity suitable for 1 in. plate; above that they are double geared. All punching and shearing machines, power driven (*i.e.*, not hydraulic), are provided with fly-wheels. If single ended, one fly-wheel is used; if double ended, usually two.

Generally, a deep gap is required in a punching machine, but a shallow one only in a shearing machine. As a rule, in a boiler and girder shop there is little shearing done far from the edges of plates, but there is a good deal of punching. But in double ended machines one gap is usually made as deep as the other, and the machine weakened thereby.

Many light machines, both fixed and portable, are made with one slide to serve both punch and shears. Then the punch is below, and the shears above. Some of these are sufficiently powerful to operate on plates up to $\frac{3}{4}$ in. thick.

Except in the matter of first cost there is no advantage in the employment of small machines for punching and shearing. A heavy machine will do light work when required, and with the advantage of punching or shearing farther from the edge than a small one, besides being much less liable to fracture, because seldom worked up to its utmost capacity.

It is highly advantageous to have a heavy punching and shearing machine fitted with a light swivelling jib crane. It saves the trouble of carrying bars and plates round from one side of the machine to the other.

A heavy punching machine, made by Messrs Craig & Donald, of Johnstone, will punch and shear 2 in. plates. It will punch 2 in. holes at the rate of twenty per minute, and the punching gap is 3 ft. $6\frac{1}{2}$ in. deep. Some idea of the massiveness of such a machine may be gathered from the fact that it weighs 53 tons.

Very heavy punching and shearing machines are seldom driven from line shafting, but by independent engines fixed to the machine framings. To obtain the required power, double gear is also employed between the engine-shaft and the cam-shaft. To give an idea of the capabilities of this class of combined machine, it may be mentioned that one of Francis Berry's, of Sowerby Bridge, will punch a 2 in. hole through a 2 in. plate, 24 in. from the edge, and shear a 2 in. plate 24 in. from the edge, taking a cut 24 in. long.

Punching and shearing machines are also actuated by hydraulic power. One large machine of this type, constructed on Tweddell's system, for ship-work, will punch $1\frac{1}{4}$ in. holes in $1\frac{1}{4}$ in. plate at a distance of 5 ft. from the edge, and shear $1\frac{1}{4}$ in. plates 5 ft. from the edge, taking at each cut a length of 18 in.

Horizontal Machines.—Many punching machines are made in which the punch operates in a horizontal direction. They are of special service in the following cases:—For punching curved angle-irons, or angle-iron rings. For punching large flanged ends. For punching cylinders. For punching any angles in which the operations of cutting off, punching, and straightening have to be performed in rapid succession. There are also machines made chiefly for shipyard use, in which provisions for angle cutting, punching, and beam bending are combined. In such machines these operations are performed horizontally, and the employment of such machines saves the expense incurred in carrying the work from one machine to another,—an important consideration in large shops, and in yards where very much work is handled, and the machines are situated at some considerable distance away from one another.

The punching of curved angles, rings, and cylinders at the vertical punching machine is awkward, for the following reasons:—

When an angle is curved with the flange internally, then in order that the large side of the punched holes shall be right for riveting, that is on the outside, the angle has to be punched in a vertical machine with the curvature downwards. Since the bolster is not raised very far above the ground, this means that holes have to be dug in the ground for the ends of the angle to fall into. In a horizontal punch this is not necessary, the curvature of the angle being horizontal, and not vertical.

Again, when a flanged end has to be punched in a vertical

machine, a portion of the flange rests upon the bolster, and the other end has to hang down into a pit in front of the punch. So with a cylinder, only that the latter is more awkward still. But in a horizontal machine a flanged end can rest upon the end of the machine, with the flange dropped down vertically in front of the punch. A cylinder too can be slung vertically in front of the punch, and in each case the work is more conveniently manipulated than at a vertical punching machine.

Again, in a machine which combines provisions for cutting off, punching, and straightening, these operations can be performed in succession on the same spot, with a consequent saving of time. It is in these special cases that there is advantage in using a horizontal punch, notwithstanding that for the general work of the shop the vertical punch is better, because it is easier to set work upon a horizontal bolster than against a vertical bolster. And the setting into the positions for the holes can be more readily done when the workman looks down directly upon the work, than when he looks at a vertical face, facing towards the body of the machine.

Combined Machines.—Horizontal punching machines are variously made;—as with a single punch, and an angle-iron cutter in combination; with provision for double-ended punching, and double angle-iron cutting, right and left; with provision for a single punch, beam bending, and double angle-iron cutting; with provision for a single punch, for beam bending, for angle-iron, and for flat bar cutting; and each in various capacities and powers. Machines also are made for angle-iron cutting exclusively, in which case the cutting is done by slides moving at an angle of 45°.

Messrs George Booth & Co. combine in one machine a horizontal punch for angles and bars, with a beam bending apparatus. The only alteration required is the substitution of a block for the punch holder.

Multiple Punching Machines.—Multiple punching machines are used chiefly for bridge and girder work. They are employed to work on plate and angles. They will punch from thirty to forty holes and upwards in plates of from $\frac{3}{8}$ in. to $\frac{1}{2}$ in. thick. The punches are capable of adjustment for pitch, and the punch slide is fitted with disengaging motion. Lengths of bar can be punched in stretches of from six feet to nine feet at once. Some machines are made "open" at the

back, leaving clear space through which plates can be passed. Others are "close" at the back, being then suitable only for edge punching. As in the case of other machines, some are driven by belt power, others with independent engines.

Drilling Machines—Various Kinds.—The drilling machines used in boiler work are very numerous. Since the introduction of mild steel, the drill has been gradually, but slowly, superseding the punch; and the slowness of the process has resulted in the introduction of the multiple machine, in which several drills are operating at the same instant. There are two systems of multiple drilling; one in which the single plates are drilled before they are bent, the other in which the seams are drilled through together, after they—the plates—are bent, and built up together. A considerable amount of ingenuity has been expended in the design of multiple machines to secure the following advantages:—(1) The providing of each drill-spindle with a separate feed-motion, so that any one can be thrown out of gear if the drill breaks, without stopping the entire series. (2) The abandonment of rigid drill-spindles in favour of spindles the centres of which can be adjusted to minute and regular distances to suit different pitches of rivets.

Radial drilling machines are used extensively by boiler-makers; but in most instances they have some special features not possessed by the ordinary radial drills used by machinists, as follows:—

In a drilling machine constructed by Messrs Rushworth & Co., of Sowerby Bridge, there are attachments for turning flanges, and for the ends or flanges of boilers, and for cutting-out holes for tubes and other openings.

For turning flanges and plain ends, the work is bolted upon a circular horizontal table, which is revolved by means of a worm cast upon its under side, and driven by a worm-wheel. The cutting tool is held in a tool-slide, suitably mounted upon the base-plate of the machine, alongside the revolving table. For cutting-out holes a boring-head is attached to the vertical drilling-spindle. The head is steadied while doing its work by means of a prolonged circular pin, which fits into a corresponding hole in the table beneath. A hole of corresponding size has to be drilled in the plate for the pin to pass through, just as is done when using the ordinary pin-drill.

There are many machines made now for turning boiler ends,

cutting out circular holes for flues, and oval manholes, and for drilling holes.

In some cases, for drilling small holes, a row of three or four drilling machines is more generally useful than one multiple drilling machine. The machines are of the radial form, either attached to a wall, or independently on the floor. They are arranged in series so that each will cover the operations of its fellow, and they can all be operated at one time, or independently of each other. They are useful for drilling, countersinking, and rymering the rivet holes in boiler and in girder work. They have the advantage over ordinary multiple drilling machines in being capable of a greater range of work, the radial arms giving them a wide sweep, while large holes can be done as well as the drilling of small ones.

Boiler Shell Drilling Machines.—The machines for drilling the holes in boiler shells in position are mostly made on one general type, though different makers vary details. The construction of a machine of this class may be described in brief outline, to show the general principle on which these machines are operated.

The boiler shell is carried with its longitudinal axis in a vertical direction, one end being held fast in the jaws of a large face-plate or chuck, furnished like a lathe-chuck with adjustable dogs, movable radially (*see* Fig. 327). This chuck is revolved on the horizontal base of the machine by means of a worm-wheel upon its under side, actuated by a worm. A circular dividing arrangement for accurate pitching is fitted, produced by means of a hand-wheel and change gears. Two pillars, one at each end of the bed plate, are racked along into position to suit the diameter of any shell which has to be drilled, ranging from 4 ft. 6 in. to 9 ft. diameter. One pillar carries two drilling heads or saddles, the other one; and two spindles are fitted in each head, making six altogether. Each spindle can be adjusted to and fro independently to suit the lengths of drills, or the whole number may be advanced or withdrawn instantaneously by power. The pitching of any pair of spindles is capable of variation. Two speeds are provided—one quick, for entering the drills, one ordinary for working. The vertical dividing, for butt seams, is effected by means of standard pitching staffs. A pump supplies lubricant, which is conveyed to each drill point by separate tubes. The machine illustrated is by Messrs Kendall & Gent Ltd.

Boiler Flue Drilling Machines.—A boiler flue flange drilling machine, made by George Booth & Co., is shown in Fig. 328. The drill spindles are carried on cross-slides on

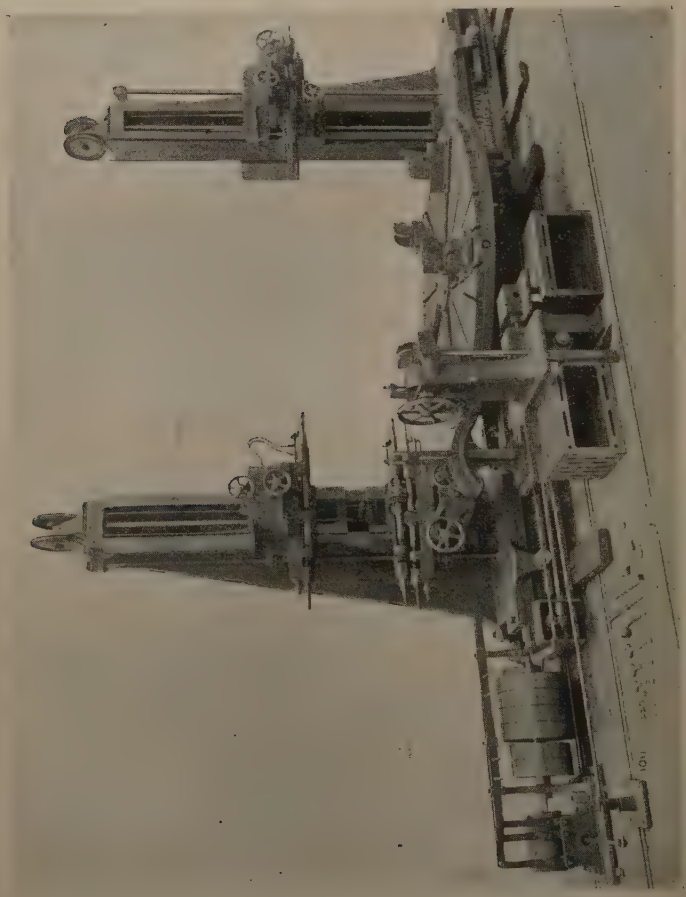


FIG. 327.

vertical pillars, the flues being carried on a circular table or chuck on the base of the machine. The chuck is rotated with worm gear, and change wheels, operated by hand. The drilling

heads are moved simultaneously. It will be seen that the drill spindles are carried right out to the edge of the slide, this being made possible by the spur gear driving arrangements.

Messrs George Booth & Co. make a special butt-strap drilling machine for drilling four holes simultaneously through the straps and shell-plates. The shell is carried in jaws adjustable in a horizontal chuck, rotated with hand-wheel and bevel gear. The drill spindles are carried one above another in a slide having sufficient vertical traverse to permit of the drilling of holes in plates 5 ft. 0 in. deep.

Portable Drilling Machines.—A very common and exceedingly useful little machine is the portable drill, used chiefly for drilling boiler shells and fire-boxes in place. The machine is held in the hands, and operated by an endless cord from overhead. During the last few years a great change has been wrought by the introduction of portable drills of pneumatic and electric types. The earlier rope-driven machines are less represented, being somewhat awkward to use by comparison with those in which it is only necessary to bring an inert cable or hose-pipe to the machine. A combination of rope-driving with a flexible shaft is fairly common, the rope driving a pulley on the stationary end of the shaft, which is then bent and directed to any required position, operating the rotating spindle of the drill at the other. The advantage of this is that the machine is light and easily handled. But the same may now be said of many self-contained pneumatic and electric types, which have two, three, or four cylinders driving through gears to the spindle, or a motor geared to it. The smallest machines are simply gripped in the hands and presented to the work, the larger require a drilling pillar for support, and as a means of resisting the pressure of the feed screw. In addition to ordinary drilling, the operations that can be done include reaming, tapping, countersinking, and tube-expanding. When these operations are done with the tool lying in a horizontal position, it is often convenient to suspend the machine with a cord, which relieves the attendant of the weight.

The plant for operating pneumatic tools includes a compressor, and a receiver, or storage tank, which provides a reserve of air from which one, or several sets of tools draw their supplies.

Countersinking. — Countersinking is usually done in

ordinary fixed wall or radial drilling machines, a method which has certain disadvantages. A useful countersinking machine

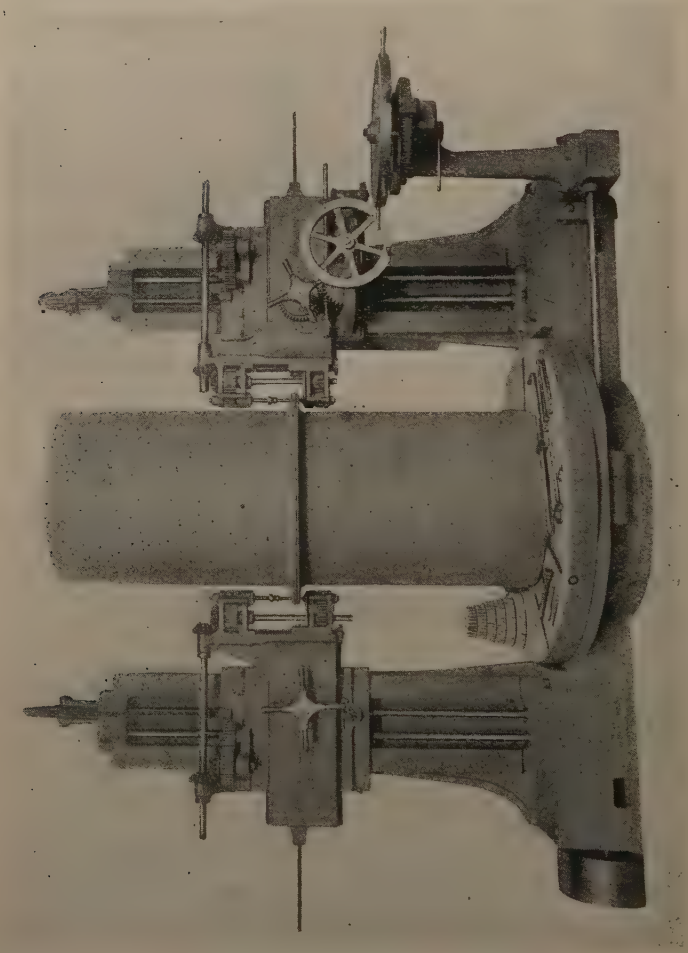


FIG. 328.

is constructed by Messrs Hetherington, of Manchester, in which a large horizontal range is available. Substantially, the sustain-

ing framework of the machine is that of a light triangular-framed pivoted wall crane; the drilling carriage travels along the horizontal members of the crane on wheels, similarly to a common jinny. The bevel driving gear of the drill is operated by a longitudinally grooved shaft, in which a driving feather slides. The countersinking tool is fed downwards by means of a long

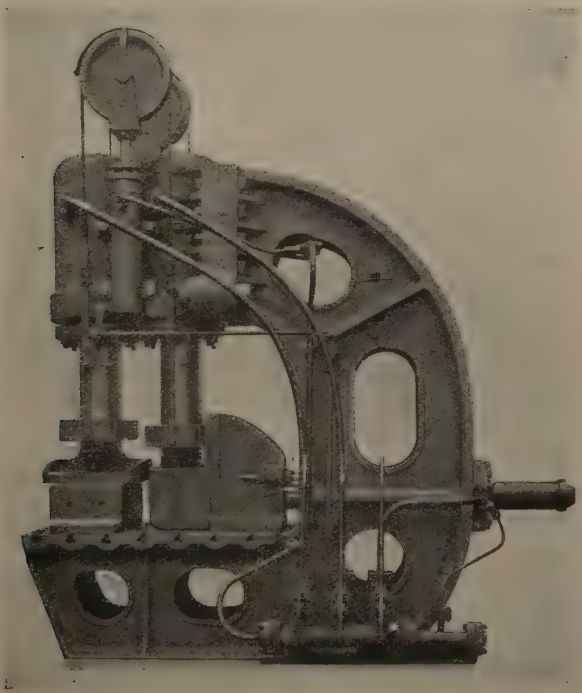


FIG. 329.

lever within easy reach of the workman, and the jib and carriage are operated and drawn over the work wherever required by the same handle.

Flanging Machines.—I have described the operation of hand flanging rather minutely, Chap. X. But in large firms where work is standardised, most of the flanging is done in hydraulic presses. There are several types of these. In some,

the entire flanging is done at one heat, and this is the practice generally adopted in locomotive, and agricultural, and general boiler works; but as it involves the making of special male and female dies of cast iron or steel, these dies become an expensive item; hence the advantage of a machine in which the flanging is done in detail around sectional dies or blocks. A machine of this type is manufactured by Messrs Fielding & Platt Ltd., of Gloucester. In this the flanging is done in lengths of about 4 ft., by means of an arrangement of hydraulic rams, by which the work is pinched, the flange bent over, and forced against the templet block.

This hydraulic flanger is shown in Fig. 329. This machine is primarily for flanging the large plates of marine boilers. It consists of a cast-iron frame made in two parts (sometimes one), fitted with two vertical and one horizontal cylinders and rams, each with a separate operating valve, and cylinders to draw the rams back when the exhaust is opened. On the bed or frame rests the anvil block made with the sides to suit the radius of the plate being flanged. One of the vertical rams has a flat die on the lower end which presses on the plate and holds it firmly on the anvil; on the lower end of the second vertical ram is a die of suitable shape for bending down the edge of the plate, so that when it is pressed down on the plate at one end, and gradually bends the plate over the edge of the anvil when the bending die returns, the holding down die is lifted slightly, and the plate is moved along about the width of the bending die, and the operation is repeated. After the length of the heat is bent over, the horizontal ram is used to straighten up any inequalities left by the bending die. A vertical guide is provided for the bending die to resist the lateral strain on it. Fig. 330 shows a hydraulic press working on a dished end. The parts lettered are—A, frame; B, B, rams, operated independently or in unison; C, ram pulling chains to return B, B; D, die-block receiving the work *a*, flanged and dished by the block on B, B; E, lower ram, which ejects *a* when completed.

Flanging presses were shown on pp. 201, 202. Fig. 331 shows the Piedboueff type of hydraulic flanging press, first introduced into this country by Mr Tweddell, and made by Messrs Fielding & Platt Ltd.

Fig. 332 shows a press with a set of flanging dies for flanging a circular plate, in section. The die A is fixed to the head

of the press by stands *a*, *a*, *a* bolted to them. The matrix B is a ring, and is carried on stands *b*, *b*, *b*, resting on the moving table, which is lifted up by the main ram C, the cylinder of which is carried in the base.

Inside the matrix is a holding plate D, which is carried on the heads of four rams *d*, *d*, working in cylinders resting on the base, and capable of being moved nearer to or farther from the centre of the main ram. The pressure is conveyed to the four cylinders by flexible copper pipes, coiled outside and con-

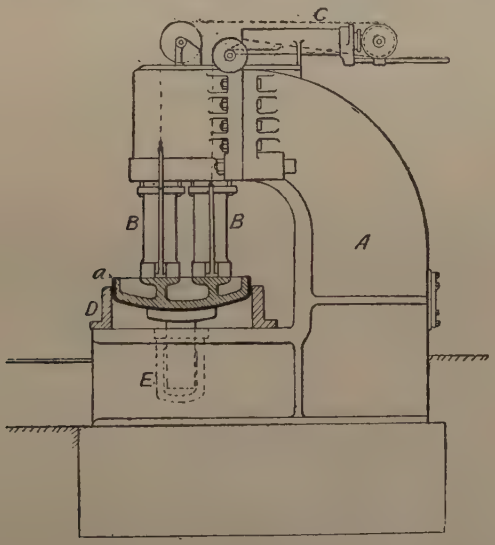


FIG. 330.

nected to stand pipes. There are separate operating valves for the main cylinder and the four holding cylinders.

The operation of flanging is as follows :—

The holding plate D is brought up level with the upper edge of the matrix B ; the heated plate *c* is then placed on the matrix and holding plate, and set true by stops or guides ; the pressure is then admitted to the four cylinders, and the holding plate lifts up the heated plate against the die A, holding it tight, and preventing buckling or moving. This is the position in which it is shown in the figure.

The pressure is then put on the main ram, and the matrix bends the edge of the plate, the curved or bell-mouthed form

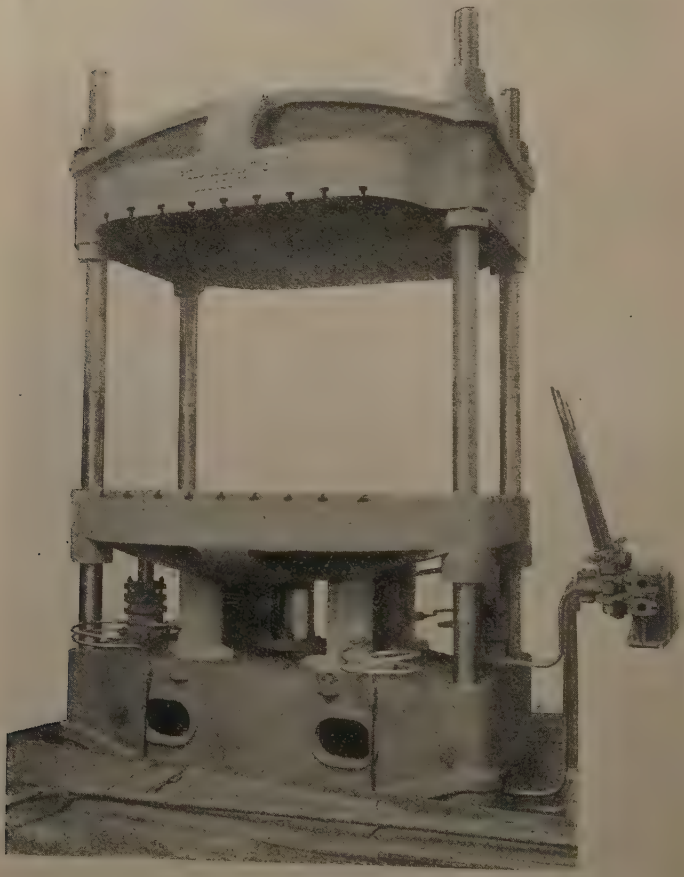


Fig. 331.

of the matrix gradually gathering it in, and so passes over the formed flange.

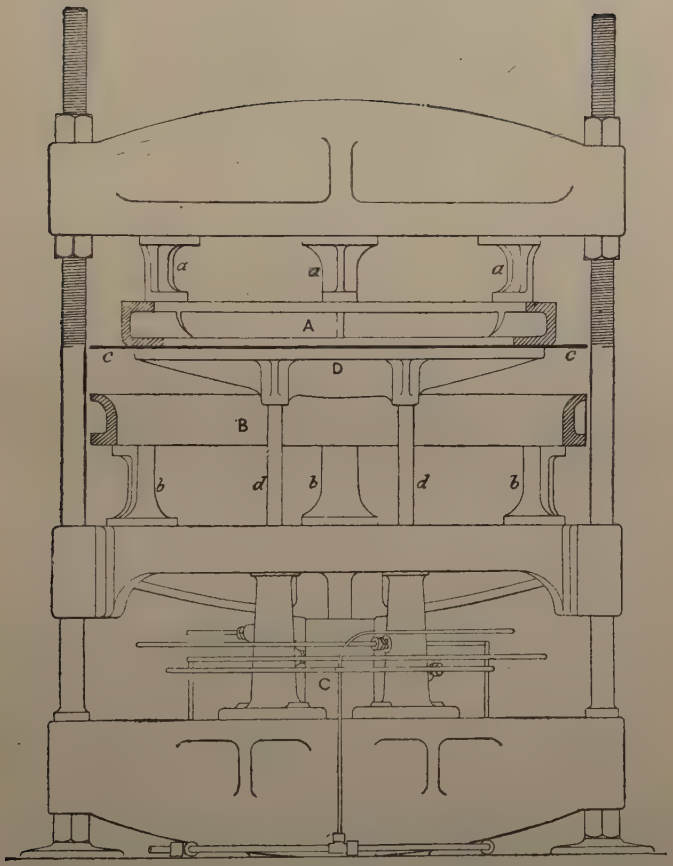


FIG. 332.

The pressure is then released from the four holding cylinders, and the flanged plate is lowered down, and on two of the stands supporting the matrix being moved the flanged plate can be withdrawn.

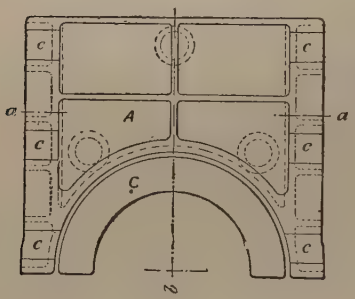


FIG. 333.

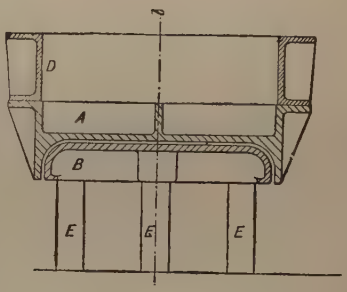


FIG. 334.

Any form of plate can be flanged on this machine, and the ordinary form of die and matrix can be used.

The three views (Fig. 333 to 335) illustrate a set of three flanging dies for flanging the throat-plate of a locomotive boiler.

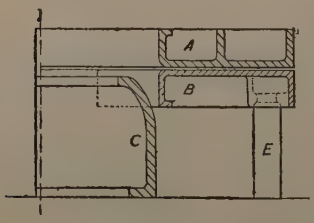


FIG. 335.

The figures comprise a plan view (Fig. 333); a transverse section, taken along the line *a-a*, but embracing also two rams behind *a-a* (Fig. 334); and a longitudinal section taken along the line *b-b* (Fig. 335). The die is composed of three pieces, the block A, which turns over the flange to which the fire-box casing is riveted; the block B, upon which the flange is turned over; and the block C, which flanges the throat to receive the barrel ring D. The bracket casting D through which the top block A is attached to the head of the press is only shown in Fig. 334. In Fig. 333 facings *c* are shown cast on the flanges for bolting it to D. B rests upon the vice-rams E, which move up and down in the base of the press, while C is bolted to the bottom table, which is operated by the main ram of the press.

The top block A being bolted to the press-top through the medium of D, the plate to be flanged is made red-hot and laid upon B, by a centre line and stops, and held in position thereon by means of pins; and the vice-rams, moving up through the base of the press, lift B, and thrust the plate into A, which forms the flange. Then the main ram and bottom table is elevated, carrying the flange block C upwards, which turns over the flange for the throat.

In Piedboueff original press the four cylinders were fixed in the base; but on designing the first press made, Messrs

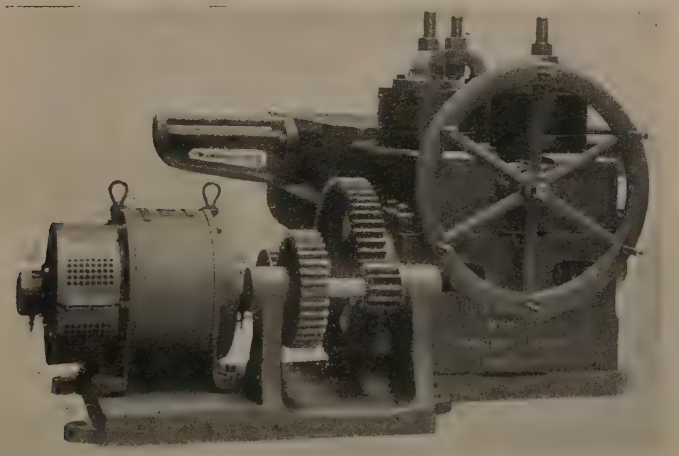


FIG. 336.

Fielding & Platt made them to move on the base, so that they could be moved to suit the different sizes of holding plate. For small circular plates one holding ram is placed inside the main ram.

Fig. 336 illustrates a machine for bending angles and tees. It is manufactured by Messrs Rushworth & Co. The main casting forms a strong table upon which the sections are bent. It carries three rollers, mounted upon vertical spindles. Each roller is in two portions, the bottom part going below the planed surface of the table, and projecting very slightly at the top edge,

to support the angle and prevent it rubbing hard on the table. The upper parts of the rolls can be raised or lowered by screws and bridges, to accommodate various thicknesses of angle. An electric motor drives the two front rolls, through spur and worm gearing, affording a purchase of 90 to 1, and the back idle roll is adjusted to and fro by the large star hand-wheel seen in front.

Machines are made specially for flanging the flues of boilers to make the Adamson joint, shown in Fig. 267, p. 243. Such a machine is shown in Fig. 221, p. 199. In these machines an end can be flanged to a depth of $4\frac{1}{2}$ in. in one minute. In some machines the flue is carried with dogs perpendicularly, or end up, on a horizontal revolving table or chuck. The flanging is done by means of an angled roller, adjusted by means of worm and sector gear. The top of the flue is supported during flanging by means of adjustable anti-friction rollers. The chuck and the flanging roller are driven by powerful gearing. In other machines, like that illustrated on p. 199, the chuck and the tool slide are each set at an angle of about 45°. The flanging mechanism is, however, essentially the same, the top end of the flue being pressed between a revolving top roller and lower supporting rollers, while the flue is revolved.

One of the difficulties encountered in hand-flanging is the prevention of the thinning-down or reduction of the sectional area of the flanged portion, with consequent weakening of that section. This is not so liable to occur in flanging by machine.

Angle-Iron Bevelling Machine.—On p. 65, I illustrated the forms of open and acute angles. In jobbing shops, when such angles are required in small quantity, it is usual to open or to close them at the anvil or levelling block with hand tools. But in some work, in shipbuilding especially, such angles are used in large quantities, and can be purchased. But it also happens that angles are sometimes required in which the angle of the flanges varies or changes at intervals, which means a good deal of troublesome work. To work such varying angles, an angle iron-bevelling machine has been devised, and is in use in shipyards. It is made by Messrs Davis & Primrose, of Leith. Though rather complicated in detail, its principle of action is simple enough. Briefly, the method of its operation consists in this—that one web of the angle is coerced firmly upon a

driven shouldered roller, while the other flange is turned over by an upper bevelled roller into the desired angle. The angle of the top roller is adjustable to any angle by its bearings being

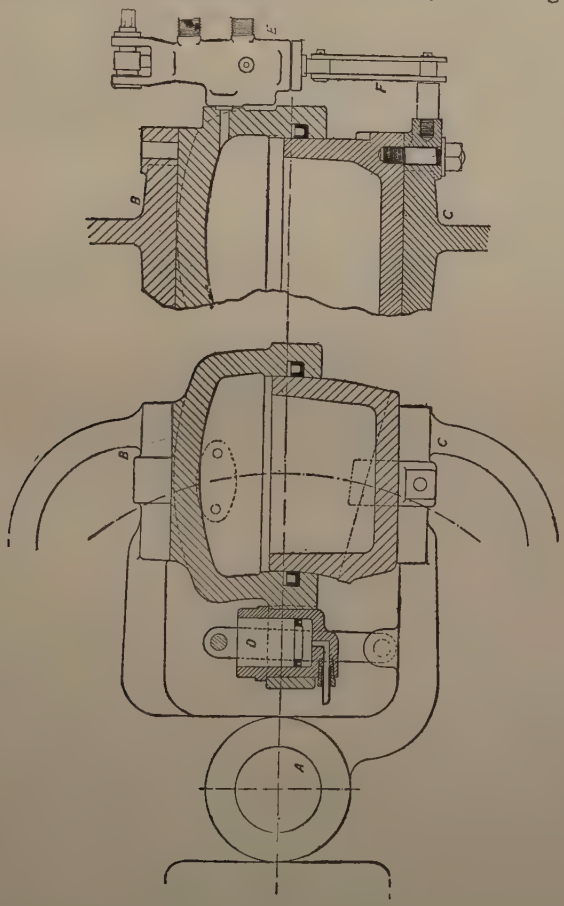


FIG. 337.

made adjustable with a hand wheel and screw in curved slots in the main framing of the machine. A finger moving over a scale indicates the amount of angle imparted.

Riveting Machines.—Several types of these were illustrated in the chapter on riveting, and we supplement this matter with a few further remarks. A sectional view of the Fielding & Platt hinged riveter is given in Fig. 337, the

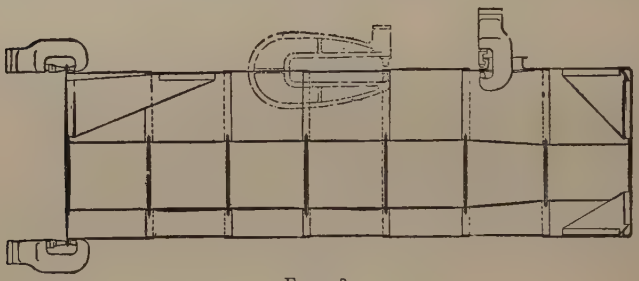


FIG. 338.

general view of which was shown on p. 226, Fig. 243. Here the pivot A carries the two arms B and C, the first having a cylinder, the second a ram fitting together, their surfaces being turned to a radius struck from the centre of pivot A. The U leather maintains a tight fit between the cylinder and ram. A small cylinder, D, acts as a return mechanism, pushing out its arm, which is coupled to a pair of links pulling up the lever C. The water supply is controlled by the valve E, the piston of which is connected by links F below, to the lever C, so that the water is automatically shut off when the arms open to their full width at the cylinder end.

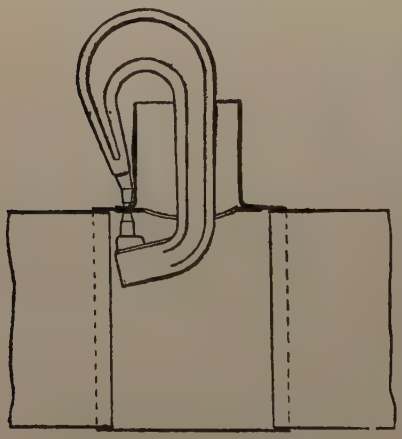


FIG. 339.

A few examples, showing how hydraulic riveters are applied to boiler-work, are seen in Figs. 338-342 (H. Berry & Co. Ltd.).

The Lancashire boiler (Fig. 338) has its rings riveted by the machine shown in dotted outline, set in a horizontal position. The front plate is united to the shell, as indicated at the end, showing the small riveters in two positions. The manhole is riveted on as seen. In locomotive boilers with domes, a special type of riveter (Fig. 339) is necessary, the outline of the frame being made to reach inside the dome.

Work on marine boilers is illustrated in Figs. 340 to 342. When the end plate is flanged, the shell is united to it by a large fixed machine (Fig. 340), the boiler being slung up in

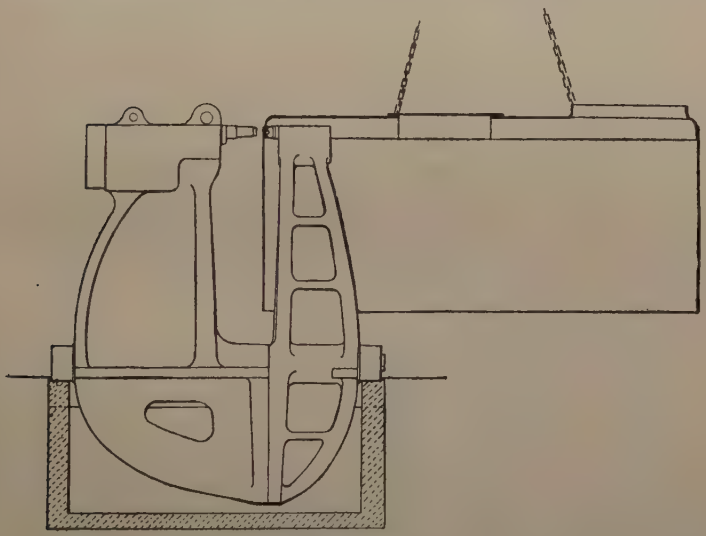


FIG. 340.

the crane; but when the shell is flanged an extra attachment is placed on the head of the riveter (Fig. 341), comprising a hinged arm, carrying at one end the closing tool, and being pushed up at the other by a toggle lever coupled to the riveting slide. The furnace flues are united to the end plates by small portable riveters working around the joints, as in Fig. 342.

Besides the gap type of pneumatic riveter mentioned on p. 223, there is a larger class of tools developed in recent years,

which are held in the hands, and presented to the rivet, while a reciprocating piston beats rapidly on the end of the snap and closes the tail over. Compressed air at from 60 to 100 lbs. supplies the necessary power, and the operator controls its admission by a thumb lever. The head of the rivet is held up by an ordinary dolly, or a pneumatic holder-up is employed, consisting of a cylinder within which is a piston, which exerts pressure on the head of the rivet, at the same time that the hammer is knocking down the tail, after which the

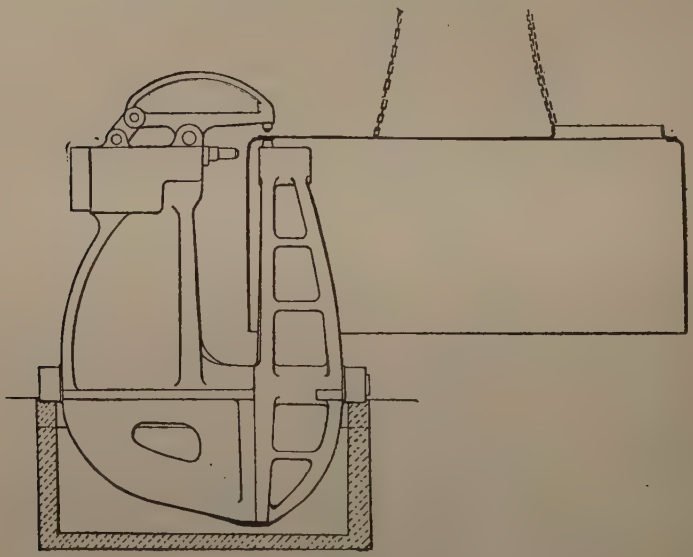


FIG. 341.

holder-up piston remains stationary pressed against the rivet while the closing is being finished.

One example of a pneumatic hammer will be sufficient to illustrate the construction; hammers differ chiefly in the forms of the valves which regulate the movements of the pistons. There are two types of hammers, the short-stroke and the long-stroke, the latter being employed for the heavier kinds of riveting, for which the piston has a much longer travel, and is able to deliver heavier blows. In the Tierney hammer,

made by the Globe Pneumatic Engineering Co. Ltd., the construction is as illustrated in Fig. 343. The snap A is held in the end of the barrel B loosely, with a spring clip, so that it may be readily changed. The piston C makes a sliding fit in B, and its movements are controlled by the piston valve D. The handle E is screwed on to B with a buttress thread, and is locked by a bolt below, closing in the split portion tightly. The air supply comes in through F, to the threaded interior of which the screwed end of the flexible air hose is coupled. The trigger G lies in a convenient position to be grasped by the operator's hand when he grips the handle, and the act of pulling it backwards opens a piston valve, H, letting the air rush up into a passage, J. It passes the valve D through the opening K and small passage *a*, so

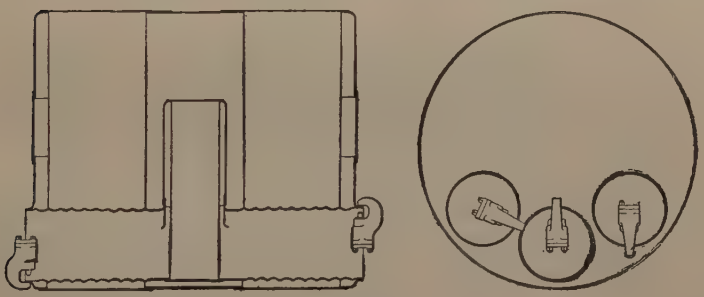


FIG. 342.

starting the piston C forwards. As it moves along, it uncovers a hole, *b*, through which the full air pressure rushes from the passage K around the valve and along the hole at the top to *b*, driving C with great force against the end of A. C passes a hole, *c*, in the barrel, which lets the air rush back along a passage to the valve D, forcing the latter along so that it opens communication with the passage *d*, through which the air pressure takes effect on the front of the piston C by way of the hole *e*, so that C is returned to its original position at the back of the barrel, ready for another blow. The number of blows per minute is about 700. With a stroke of 6 in. rivets up to 1 in. diameter can be closed, but sizes up to $1\frac{3}{8}$ in. are closed by larger hammers, having a stroke of 9 in. The air

pressure used in these tools is 100 lbs. per square inch; 90 to 120 rivets per hour is the usual capacity.

The same kind of mechanism is incorporated in the yoke riveters, which are formed of horse-shoe shape, to clear round the work; at one end there is a dolly or holder-on, and at the other the hammer, which beats the rivet tail over while the head is supported by the dolly. The advantage is of course that the operator does not have to support the hammer with his weight, and receive the vibration while working, the yoke being suspended from a crane or a beam.

Electric Riveting.—I have alluded to hydraulic and pneumatic riveting in Chap. XII. The newest thing in riveting

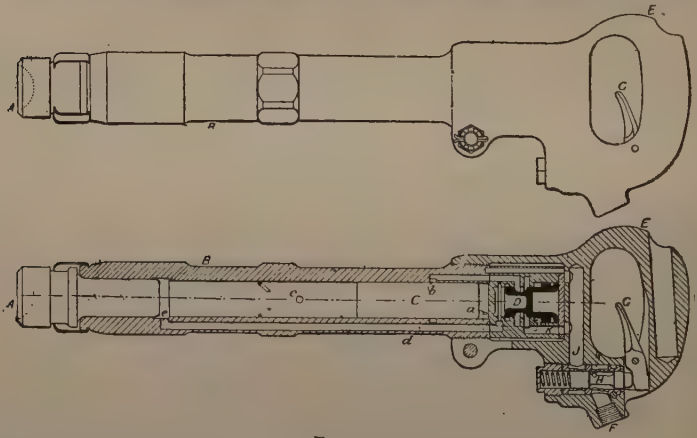


FIG. 343.

is a portable electric riveter. It has not yet come into use in England, but it has been successfully employed in France and Germany. A piston, actuated by the electric motor through speed-reducing gear, is pushed forward horizontally, and compresses oil on the upper surface of the vertical ram to a pressure of 2 tons per square inch. The ram has an area of 16 sq. in., giving a pressure on the rivet of 32 tons per square inch. The current is brought from a fixed generating dynamo by conductors. About $3\frac{1}{2}$ electrical horse-power is required for a period of two or three seconds at each rivet. The machine is manufactured by A. Piat & ses Fils, of Paris.

Pneumatic Chipping and Caulking.—Pneumatic hammers of the short-stroke pattern are used for both chipping and caulking, the tools being of similar form to those employed by hand, excepting for the socket end, which fits in the mouth of the hammer. Tube-beading is also effected by means of suitable tools, having a hooked extremity which hammers down the end of the tube into the beaded form.

Rivet Furnaces.—In addition to the reverberatory furnaces mentioned on p. 224, there are several types of portable furnaces especially suited to the needs of outdoor work. We illustrate one by Messrs Henry Berry & Co. Ltd., the "cupola" form (Fig. 344). It measures 2 ft. square by 4 ft. 9 in. high, and is provided with a tall chimney. A casing of $\frac{1}{4}$-in. steel plate encloses the fire-brick lining. The rivets are dropped in through the flap door at the top, and they descend by gravity to the hearth, being gradually heated up during their course by the products of combustion coming from the grate below, up through openings on each side of the hearth, and so through the pile of rivets to the chimney. The rivets are removed as required through the door at the front, fresh ones being put in at the top to keep the chamber full. As no fuel can come into contact with the rivets, they are preserved clean and free from scale. About 3,000 $\frac{3}{4}$-inch rivets can be heated in a day, with an expenditure of about 2 to 2$\frac{1}{2}$ cwt. of coal.

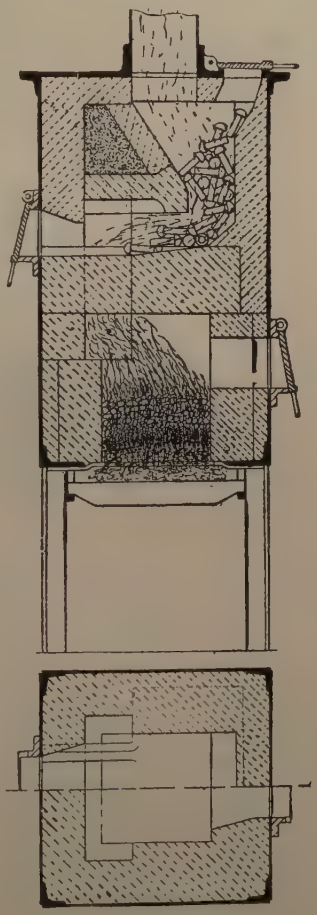


FIG. 344.

Cold-Iron Saws.—The cold-iron saws are a valuable acquisition to the boiler shop, because they not only save an immense amount of labour in cutting and dressing off, but the cut ends are left perfectly true from the saw, practically as clean as though planed; such saws are used also for sawing off head metal from castings, so saving time in the lathe. The Hetherington saw is a good machine. The table upon which the work is held is provided with tee-slots for tee-headed bolts. The saw-spindle is carried in bearings in a swing frame, the saw with its frame being pulled down or fed upon the work by means of a lever handle, which can be weighted if desired. The saw is driven by belt pulleys, bevel wheels, and worm-gearing. It is lubricated by means of a small oil pump, driven with a cord from a pulley on the driving spindle. The circumferential velocity of the saw should be speeded at 50 ft. per minute. At this rate, a girder 12 in. by 6 in. by $\frac{11}{16}$ in. thick can be cut through in ten minutes.

Welding Hammer.—Welding hammers are used in many shops for welding up the rings for flues of cross-tubes, and for flat plates. The hammer is operated vertically, with great rapidity, being a miniature steam-hammer mounted on an arched framing. The flue is laid upon a portable anvil, which is traversed longitudinally on wheels under the hammer.

APPENDIX.

PROPORTIONS OF RIVETED JOINTS.

ALL DIMENSIONS IN INCHES.

TABLE IX.

SINGLE RIVETED LAP JOINTS, IRON PLATES AND IRON RIVETS.
(Fig. 345.)

Thickness of Plates.	Diameter of Rivets.	Pitch of Rivets. P	Centre of Rivets to edge of Plate. O
$\frac{1}{4}$	$\frac{5}{8}$	$1\frac{1}{2}$	$1\frac{5}{16}$
$\frac{5}{16}$	$\frac{11}{16}$	$1\frac{5}{8}$	1
$\frac{3}{8}$	$\frac{3}{4}$	$1\frac{13}{16}$	$1\frac{1}{8}$
$\frac{7}{16}$	$\frac{13}{16}$	2	$1\frac{1}{4}$
$\frac{1}{2}$	$\frac{7}{8}$	2	$1\frac{5}{16}$
$\frac{9}{16}$	$\frac{15}{16}$	$2\frac{1}{8}$	$1\frac{7}{16}$
$\frac{5}{8}$	1	$2\frac{1}{4}$	$1\frac{1}{2}$
$\frac{11}{16}$	$1\frac{1}{16}$	$2\frac{5}{8}$	$1\frac{5}{8}$
$\frac{3}{4}$	$1\frac{1}{8}$	$2\frac{7}{16}$	$1\frac{11}{16}$

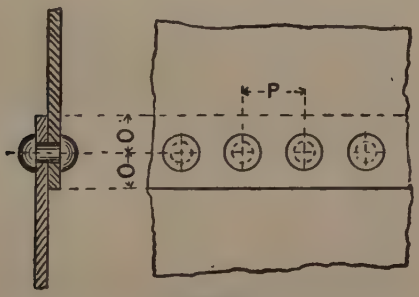


FIG. 345.

TABLE X.

SINGLE RIVETED LAP JOINTS, STEEL PLATES AND STEEL RIVETS.
(Fig. 345.)

Thickness of Plates.	Diameter of Rivets.	Pitch of Rivets. P	Centre of Rivets to edge of Plate. O
$\frac{1}{4}$	$\frac{11}{16}$	$1\frac{9}{16}$	1
$\frac{5}{16}$	$\frac{3}{4}$	$1\frac{11}{16}$	$1\frac{1}{8}$
$\frac{3}{8}$	$\frac{13}{16}$	$1\frac{13}{16}$	$1\frac{1}{4}$
$\frac{7}{16}$	$\frac{7}{8}$	2	$1\frac{5}{16}$
$\frac{1}{2}$	$\frac{15}{16}$	2	$1\frac{3}{8}$
$\frac{9}{16}$	1	$2\frac{1}{8}$	$1\frac{1}{2}$
$\frac{5}{8}$	$1\frac{1}{16}$	$2\frac{1}{4}$	$1\frac{5}{8}$
$\frac{11}{16}$	$1\frac{1}{8}$	$2\frac{5}{16}$	$1\frac{11}{16}$
$\frac{3}{4}$	$1\frac{3}{16}$	$2\frac{7}{16}$	$1\frac{13}{16}$

TABLE XI.

DOUBLE RIVETED LAP JOINTS, IRON PLATES AND IRON RIVETS.

(Figs. 346, 347.)

Thickness of Plates.	Diameter of Rivets.	Pitch of Rivets. P	Centre of Rivets to edge of Plates. O	Distance between rows of Rivets.	
				Zigzag. D	Chain. D
$\frac{7}{16}$	$\frac{3}{4}$	$2\frac{3}{4}$	$1\frac{1}{8}$	$1\frac{5}{8}$	2
$\frac{1}{2}$	$\frac{13}{16}$	$2\frac{7}{8}$	$1\frac{1}{4}$	$1\frac{1}{2}$	$2\frac{1}{8}$
$\frac{9}{16}$	$\frac{7}{8}$	3	$1\frac{5}{16}$	$1\frac{9}{16}$	$2\frac{1}{4}$
$\frac{5}{8}$	$1\frac{5}{16}$	$3\frac{1}{8}$	$1\frac{3}{8}$	$1\frac{5}{8}$	$2\frac{3}{8}$
$\frac{11}{16}$	1	$3\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{7}{8}$	$2\frac{1}{2}$
$\frac{3}{4}$	$1\frac{1}{16}$	$3\frac{7}{16}$	$1\frac{5}{8}$	$1\frac{13}{16}$	$2\frac{5}{8}$
$\frac{7}{8}$	$1\frac{5}{16}$	$3\frac{3}{4}$	$1\frac{3}{4}$	$1\frac{15}{16}$	$2\frac{7}{8}$

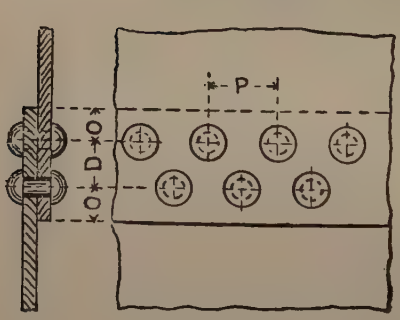


FIG. 346.

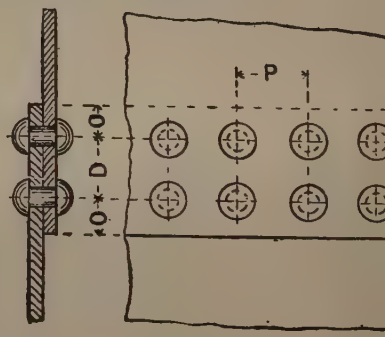


FIG. 347.

TABLE XII.

DOUBLE RIVETED LAP JOINTS, STEEL PLATES AND STEEL RIVETS

(Figs. 346, 347.)

Thickness of Plates.	Diameter of Rivets.	Pitch of Rivets. P	Centre of Rivets to edge of Plates. O	Distance between rows of Rivets.	
				Zigzag. D	Chain. D
$\frac{7}{16}$	$\frac{13}{16}$	$2\frac{11}{16}$	$1\frac{3}{16}$	$1\frac{5}{8}$	$2\frac{1}{8}$
$\frac{1}{2}$	$\frac{7}{8}$	$2\frac{7}{8}$	$1\frac{5}{16}$	$1\frac{1}{2}$	$2\frac{1}{4}$
$\frac{9}{16}$	$1\frac{5}{16}$	$2\frac{15}{16}$	$1\frac{3}{8}$	$1\frac{9}{16}$	$2\frac{3}{8}$
$\frac{5}{8}$	1	3	$1\frac{1}{2}$	$1\frac{5}{8}$	$2\frac{1}{2}$
$\frac{11}{16}$	$1\frac{1}{16}$	$3\frac{1}{16}$	$1\frac{9}{16}$	$1\frac{11}{16}$	$2\frac{5}{8}$
$\frac{3}{4}$	$1\frac{1}{8}$	$3\frac{1}{8}$	$1\frac{11}{16}$	$1\frac{3}{4}$	$2\frac{3}{4}$
$\frac{7}{8}$	$1\frac{1}{4}$	$3\frac{5}{8}$	$1\frac{7}{8}$	$1\frac{15}{16}$	3

TABLE XIII.

SINGLE RIVETED DOUBLE-BUTT JOINTS, IRON PLATES AND IRON RIVETS. (Fig. 348.)

Thickness of Plates.	Diameter of Rivets.	Pitch of Rivets. P	Centre of Rivets to edge of Plates O	Thickness of Butt Strap.
$\frac{3}{8}$	$\frac{5}{8}$	$1\frac{15}{16}$	$\frac{15}{16}$	$\frac{1}{4}$
$\frac{7}{16}$	$\frac{11}{16}$	$2\frac{1}{8}$	$1\frac{1}{32}$	$\frac{1}{4}$
$\frac{1}{2}$	$\frac{3}{4}$	$2\frac{5}{16}$	$1\frac{1}{8}$	$\frac{5}{16}$
$\frac{9}{16}$	$\frac{13}{16}$	$2\frac{7}{16}$	$1\frac{1}{4}$	$\frac{3}{8}$
$\frac{5}{8}$	$\frac{7}{8}$	$2\frac{9}{16}$	$1\frac{5}{16}$	$\frac{3}{8}$
$\frac{11}{16}$	$\frac{15}{16}$	$2\frac{11}{16}$	$1\frac{3}{8}$	$\frac{7}{16}$
$\frac{3}{4}$	1	$2\frac{13}{16}$	$1\frac{1}{2}$	$\frac{7}{16}$
$\frac{7}{8}$	$1\frac{1}{8}$	$3\frac{1}{8}$	$1\frac{11}{16}$	$\frac{9}{16}$

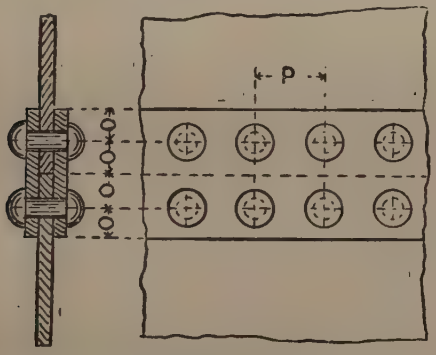


FIG. 348

TABLE XIV.

SINGLE RIVETED DOUBLE-BUTT JOINTS, STEEL PLATES AND STEEL RIVETS. (Fig. 348.)

Thickness of Plates.	Diameter of Rivets.	Pitch of Rivets. P	Centre of Rivets to edge of Plates O	Thickness of Butt Strap.
$\frac{3}{8}$	$\frac{11}{16}$	$1\frac{15}{16}$	$1\frac{1}{32}$	$\frac{1}{4}$
$\frac{7}{16}$	$\frac{3}{4}$	$2\frac{1}{8}$	$1\frac{1}{8}$	$\frac{1}{4}$
$\frac{1}{2}$	$1\frac{3}{16}$	$2\frac{5}{16}$	$1\frac{1}{4}$	$\frac{5}{16}$
$\frac{9}{16}$	$\frac{7}{8}$	$2\frac{3}{8}$	$1\frac{5}{16}$	$\frac{3}{8}$
$\frac{5}{8}$	$\frac{15}{16}$	$2\frac{1}{2}$	$1\frac{3}{8}$	$\frac{3}{8}$
$\frac{11}{16}$	1	$2\frac{5}{8}$	$1\frac{1}{2}$	$\frac{7}{16}$
$\frac{3}{4}$	$1\frac{1}{16}$	$2\frac{3}{4}$	$1\frac{5}{8}$	$\frac{1}{2}$
$\frac{7}{8}$	$1\frac{3}{16}$	3	$1\frac{13}{16}$	$\frac{9}{16}$

TABLE XV.—DOUBLE RIVETED DOUBLE-BUTT JOINTS, IRON PLATES AND IRON RIVETS. (Figs. 349, 350.)

Thickness of Plates.	Diameter of Rivets.	Pitch of Rivets. P	Centre of Rivets to edge of Plates. O	Distance between rows of Rivets.		Thickness of Butt Strap
				Zigzag. D	Chain. D	
$\frac{9}{16}$	$\frac{3}{4}$	$3\frac{1}{2}$	$1\frac{1}{8}$	$1\frac{5}{8}$	2	$\frac{3}{8}$
$\frac{5}{8}$	$\frac{15}{16}$	$3\frac{11}{16}$	$1\frac{3}{16}$	$1\frac{3}{4}$	$2\frac{1}{8}$	$\frac{3}{8}$
$\frac{11}{16}$	$\frac{7}{8}$	$3\frac{15}{16}$	$1\frac{5}{16}$	$1\frac{7}{8}$	$2\frac{1}{4}$	$\frac{7}{16}$
$\frac{3}{4}$	$\frac{15}{16}$	$4\frac{1}{8}$	$1\frac{3}{8}$	2	$2\frac{3}{8}$	$\frac{7}{16}$
$\frac{7}{8}$	$1\frac{1}{16}$	$4\frac{5}{8}$	$1\frac{9}{16}$	$2\frac{3}{16}$	$2\frac{3}{8}$	$\frac{9}{16}$
1	$1\frac{3}{16}$	$5\frac{1}{16}$	$1\frac{3}{4}$	$2\frac{7}{16}$	$2\frac{7}{8}$	$\frac{5}{8}$

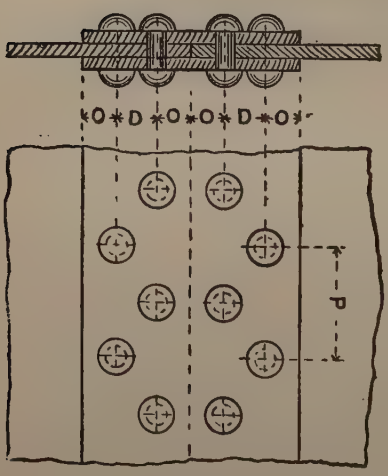


FIG. 349.

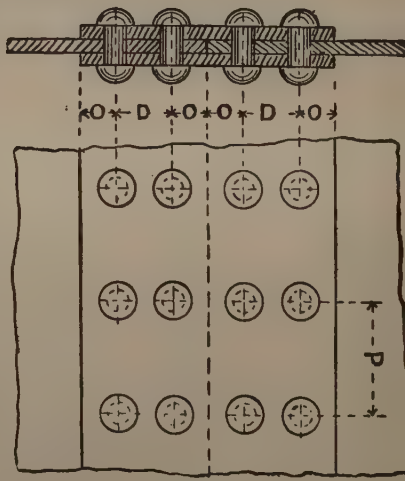


FIG. 350.

TABLE XVI.—DOUBLE RIVETED DOUBLE-BUTT JOINTS, STEEL PLATES AND STEEL RIVETS. (Figs. 349, 350.)

Thickness of Plates.	Diameter of Rivets.	Pitch of Rivets. P	Centre of Rivets to edge of Plates. O	Distance between rows of Rivets.		Thickness of Butt Strap
				Zigzag. D	Chain. D	
$\frac{9}{16}$	$\frac{13}{16}$	$3\frac{1}{2}$	$1\frac{3}{16}$	$1\frac{5}{8}$	$2\frac{1}{8}$	$\frac{3}{8}$
$\frac{5}{8}$	$\frac{7}{8}$	$3\frac{5}{8}$	$1\frac{5}{16}$	$1\frac{3}{4}$	$2\frac{1}{4}$	$\frac{7}{16}$
$\frac{11}{16}$	$\frac{15}{16}$	$3\frac{13}{16}$	$1\frac{3}{8}$	$1\frac{7}{8}$	$2\frac{3}{8}$	$\frac{1}{2}$
$\frac{3}{4}$	1	4	$1\frac{1}{2}$	2	$2\frac{1}{2}$	$\frac{9}{16}$
$\frac{7}{8}$	$1\frac{1}{8}$	$4\frac{3}{8}$	$1\frac{11}{16}$	$2\frac{5}{16}$	$2\frac{3}{4}$	$\frac{5}{8}$
1	$1\frac{1}{4}$	$4\frac{3}{4}$	$1\frac{7}{8}$	$2\frac{3}{8}$	3	$\frac{5}{8}$

TABLE XVII.

RIVETING FOR TANK WORK.

Thickness of Plates.	Diameter of Rivets.	Pitch.	Lap.
$\frac{1}{16}$ $\frac{1}{8}$	$\frac{3}{16}$ $\frac{3}{8}$	$\frac{3}{4}$ $1\frac{1}{8}$	$\frac{5}{8}$ $1\frac{1}{8}$
$\frac{1}{8}$ and less for Pipes Riveted Cold	$\frac{5}{16}$	1	1
$\frac{3}{16}$ $\frac{1}{4}$ $\frac{5}{16}$ $\frac{3}{8}$	$\frac{7}{16}$ $\frac{1}{2}$ $\frac{5}{8}$ $\frac{3}{4}$	$1\frac{1}{2}$ 2 $2\frac{1}{2}$ 3	$1\frac{5}{16}$ $1\frac{1}{2}$ $1\frac{7}{8}$ $2\frac{1}{4}$

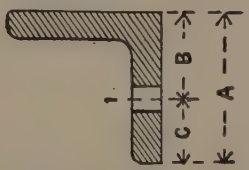


FIG. 351.

TABLE XVIII.

BOLT CENTRES IN ANGLE IRONS. (Fig. 351.)

A	B	C
$1\frac{1}{2}$ $1\frac{3}{4}$ 2 $2\frac{1}{2}$ 3 $3\frac{1}{4}$ $3\frac{1}{2}$ 4 $4\frac{1}{2}$ 5	$\frac{7}{8}$ 1 $1\frac{1}{8}$ $1\frac{3}{8}$ $1\frac{3}{4}$ $1\frac{7}{8}$ 2 $2\frac{1}{2}$ $2\frac{3}{4}$?	$\frac{5}{8}$ $\frac{3}{4}$ $\frac{7}{8}$ $1\frac{1}{8}$ $1\frac{1}{4}$ $1\frac{3}{8}$ $1\frac{1}{2}$ $1\frac{1}{2}$ $1\frac{3}{4}$ 2

Table XIX.

Diameters, Circumferences, Areas, Sides of Equal Squares, Squares, and Cubes.

Diameter in inches.	Circumference in inches.	Area in Sq. inches.	Sides of Equal Squares, inches.	Area in Sq. feet.	Square, in inches.	Cube, in inches.
$\frac{1}{8}$	.3927	.0122	.1107	...	.0156	.00195
$\frac{1}{4}$	.7854	.0490	.2215	...	.0625	.01563
$\frac{3}{8}$	1.1781	.1104	.3323	...	.1406	.05273
$\frac{1}{2}$	1.5708	.1963	.4431	...	.25	.125
$\frac{5}{8}$	1.9635	.3068	.5438	...	.3906	.24414
$\frac{3}{4}$	2.3562	.4417	.6646	...	.5625	.42188
$\frac{7}{8}$	2.7489	.6013	.7754	...	.7656	.66992
1	3.1416	.7854	.8862	...	1.	1.
$1\frac{1}{8}$	3.5343	.9940	.9969	.0069	1.2656	1.42383
$1\frac{1}{4}$	3.9270	1.2271	1.1017	.0084	1.5625	1.95313
$1\frac{3}{8}$	4.3197	1.4848	1.2185	.0102	1.8906	2.59961
$1\frac{1}{2}$	4.7124	1.7671	1.3293	.0122	2.25	3.375
$1\frac{5}{8}$	5.1051	2.0739	1.4401	.0143	2.6406	4.2910
$1\frac{3}{4}$	5.4978	2.4052	1.5508	.0166	3.0625	5.3593
$1\frac{7}{8}$	5.8905	2.7611	1.6616	.0191	3.5156	6.5918
2	6.2832	3.1416	1.7724	.0225	4.	8.
$2\frac{1}{8}$	6.6759	3.5465	1.8831	.0245	4.5156	9.5957
$2\frac{1}{4}$	7.0686	3.9760	1.9939	.0275	5.0625	11.3906
$2\frac{3}{8}$	7.4613	4.4302	2.1047	.0307	5.6406	13.3965
$2\frac{1}{2}$	7.8540	4.9087	2.2155	.0340	6.25	15.625
$2\frac{5}{8}$	8.2467	5.4119	2.3262	.0375	6.8906	18.0879
$2\frac{3}{4}$	8.6394	5.9395	2.4370	.0411	7.5625	20.7969
$2\frac{7}{8}$	9.0321	6.4918	2.5478	.0450	8.2656	23.7637
3	9.4248	7.0686	2.6586	.0490	9.	27.
$3\frac{1}{8}$	9.8175	7.6699	2.7694	.0531	9.7656	30.5176
$3\frac{1}{4}$	10.210	8.2957	2.8801	.0575	10.5625	34.3281
$3\frac{3}{8}$	10.602	8.9462	2.9909	.0620	11.3906	38.4434
$3\frac{1}{2}$	10.995	9.6211	3.1017	.0668	12.25	42.875
$3\frac{5}{8}$	11.388	10.320	3.2124	.0730	13.1406	47.634
$3\frac{3}{4}$	11.781	11.044	3.3232	.0767	14.0625	52.734
$3\frac{7}{8}$	12.173	11.793	3.4340	.0818	15.0156	58.185
4	12.566	12.566	3.5448	.0879	16.	64.
$4\frac{1}{8}$	12.959	13.364	3.6555	.0935	17.0156	70.1895
$4\frac{1}{4}$	13.351	14.186	3.7663	.0993	18.0625	76.7656
$4\frac{3}{8}$	13.744	15.033	3.8771	.1052	19.1406	83.7402
$4\frac{1}{2}$	14.137	15.904	3.9880	.1113	20.25	91.125
$4\frac{5}{8}$	14.529	16.800	4.0987	.1176	21.3906	98.9316
$4\frac{3}{4}$	14.922	17.720	4.2095	.1240	22.5625	107.1719
$4\frac{7}{8}$	15.315	18.665	4.3202	.1306	23.7656	115.8574
5	15.708	19.635	4.4310	.1374	25.	125.

TABLE XIX.—*Continued.*

Diameter in inches.	Circumference in inches.	Area in Sq. inches.	Sides of Equal Squares, inches.	Area in Sq. feet.	Square, in inches.	Cube, in inches.
5 1/8	16.100	20.629	4.5417	.1444	26.2656	134.6113
5 1/4	16.493	21.647	4.6525	.1515	27.5625	144.7031
5 3/8	16.886	22.690	4.7633	.1588	28.8906	155.2871
5 1/2	17.278	23.758	4.8741	.1663	30.25	166.375
5 5/8	17.671	24.850	4.9848	.1739	31.6406	177.9785
5 3/4	18.064	25.967	5.0956	.1817	33.0625	190.1094
5 7/8	18.457	27.108	5.2064	.1897	34.5186	202.7793
6	18.849	28.274	5.3172	.1979	36.	216.
6 1/8	19.242	29.464	5.4280	.2062	37.5156	229.7832
6 1/4	19.635	30.679	5.5388	.2147	39.0625	244.1406
6 3/8	20.027	31.919	5.6495	.2234	40.6406	259.0840
6 1/2	20.420	33.183	5.7603	.2322	42.25	274.625
6 5/8	20.813	34.471	5.8711	.2412	43.8906	290.7754
6 3/4	21.205	35.784	5.9819	.2504	45.5625	307.5469
6 7/8	21.598	37.122	6.0927	.2598	47.2656	324.9512
7	21.991	38.484	6.2034	.2693	49.	343.
7 1/8	22.383	39.871	6.3142	.2791	50.7656	361.7051
7 1/4	22.776	41.282	6.4350	.2889	52.5625	381.0781
7 3/8	23.169	42.718	6.5358	.2990	54.3906	401.1309
7 1/2	23.562	44.178	6.6465	.3092	56.25	421.879
7 5/8	23.954	45.663	6.7573	.3196	58.1406	443.3223
7 3/4	24.347	47.173	6.8681	.3299	60.0625	465.4844
7 7/8	24.740	48.707	6.9789	.3409	62.0156	488.3730
8	25.132	50.265	7.0897	.3518	64.	512.
8 1/8	25.515	51.848	7.2005	.3629	66.0156	536.3770
8 1/4	25.918	53.456	7.3112	.3741	68.0625	561.5156
8 3/8	26.310	55.088	7.4220	.3856	70.1406	587.4277
8 1/2	26.703	56.745	7.5328	.3972	72.25	614.125
8 5/8	27.096	58.426	7.6436	.4089	74.3906	641.6191
8 3/4	27.489	60.132	7.7544	.4209	76.5625	669.9219
8 7/8	27.881	61.862	7.8651	.4330	78.7656	699.0449
9	28.274	63.617	7.9760	.4453	81.	729.
9 1/8	28.667	65.396	8.0866	.4577	83.2656	759.7988
9 1/4	29.059	67.200	8.1974	.4704	85.5625	791.4531
9 3/8	29.452	69.029	8.3081	.4832	87.8906	823.9746
9 1/2	29.845	70.882	8.4190	.4961	90.25	857.375
9 5/8	30.237	72.759	8.5297	.5093	92.6406	891.6660
9 3/4	30.630	74.662	8.6403	.5226	95.0625	926.8594
9 7/8	31.023	76.588	8.7513	.5361	97.5156	962.0968
10	31.416	78.540	8.8620	.5497	100.	1000.
10 1/8	31.808	80.515	8.9728	.5636	102.5156	1037.9707
10 1/4	32.201	82.516	9.0836	.5776	105.0625	1076.8906
10 3/8	32.594	84.540	9.1943	.5917	107.6406	1116.7715
10 1/2	32.986	86.590	9.3051	.6061	110.25	1157.625

TABLE XIX.—*Continued.*

Diameter in inches.	Circumference in inches.	Area in Sq. inches.	Sides of Equal Squares, inches.	Area in Sq. feet.	Square in inches.	Cube, in inches.
10 5/8	33.379	88.664	9.4159	.6206	112.8906	1199.4629
10 3/4	33.772	90.762	9.5267	.6353	115.5625	1242.2969
10 7/8	34.164	92.885	9.6375	.6499	118.2656	1286.1387
11	34.557	95.033	9.7482	.6652	121.	1331.
11 1/8	34.950	97.205	9.8590	.6804	123.7656	1376.8926
11 1/4	35.343	99.402	9.9698	.6958	126.5625	1423.8281
11 3/8	35.735	101.623	10.080	.7143	129.3906	1471.8184
11 1/2	36.128	103.869	10.191	.7270	132.25	1520.875
11 5/8	36.521	106.139	10.302	.7429	135.1406	1571.0098
11 3/4	36.913	108.434	10.413	.7590	138.0625	1622.234
11 7/8	37.306	110.753	10.523	.7752	141.0155	1674.5605
12	37.699	113.097	10.634	.7916	144.	1728.
12 1/8	38.091	115.466	10.745	.8082	147.0156	1782.5645
12 1/4	38.484	117.859	10.856	.8250	150.0625	1838.2656
12 3/8	38.877	120.276	10.966	.8419	153.1406	1895.1152
12 1/2	39.270	122.718	11.077	.8590	156.25	1953.1250
12 5/8	39.662	125.184	11.188	.8762	159.3906	2012.3066
12 3/4	40.055	127.676	11.299	.8937	162.5625	2072.6719
12 7/8	40.448	130.192	11.409	.9113	165.7656	2134.2324
13	40.840	132.732	11.520	.9291	169.	2197.
13 1/8	41.233	135.297	11.631	.9470	172.2656	2260.9863
13 1/4	41.626	137.886	11.742	.9642	175.5625	2326.2031
13 3/8	42.018	140.500	11.853	.9835	178.8906	2392.6621
13 1/2	42.411	143.139	11.963	.9939	182.25	2460.3750
13 5/8	42.804	145.802	12.074	1.0125	185.6406	2529.3535
13 3/4	43.197	148.489	12.185	1.03	189.0625	2599.6094
13 7/8	43.589	151.201	12.296	1.05	192.5156	2671.1543
14	43.982	153.938	12.406	1.06	196.	2744.
14 1/8	44.375	156.699	12.517	1.08	199.5156	2818.1582
14 1/4	44.767	159.485	12.628	1.10	203.0625	2893.6406
14 3/8	45.160	162.295	12.739	1.12	206.6406	2970.4590
14 1/2	45.553	165.130	12.850	1.14	210.25	3048.6250
14 5/8	45.945	167.989	12.960	1.16	213.8906	3128.1504
14 3/4	46.338	170.873	13.071	1.18	217.5625	3209.0469
14 7/8	46.731	173.782	13.182	1.20	221.2265	3291.3262
15	47.124	176.715	13.293	1.22	225.	3375.
15 1/8	47.516	179.672	13.403	1.24	228.7656	3460.0791
15 1/4	47.909	182.654	13.541	1.26	232.5625	3546.5781
15 3/8	48.302	185.661	13.625	1.29	236.3906	3633.5059
15 1/2	48.694	188.692	13.736	1.31	240.25	3723.8750
15 5/8	49.087	191.748	13.847	1.33	244.1406	3814.6903
15 3/4	49.480	194.828	13.957	1.35	248.0625	3906.9844
15 7/8	49.872	197.933	14.068	1.37	252.0156	4000.7480
16	50.265	201.062	14.179	1.39	256.	4096.

TABLE XIX.—*Continued.*

Diameter in inches.	Circumference in inches.	Area in Sq. inches.	Sides of Equal Squares, inches.	Area in Sq. feet.	Square, in inches.	Cube, in inches.
16 1/8	50.658	204.216	14.290	1.41	260.0156	4192.7520
16 1/4	51.051	207.394	14.400	1.44	264.0625	4291.0156
16 3/8	51.443	210.597	14.511	1.46	268.1406	4390.8027
16 1/2	51.836	213.825	14.622	1.48	272.25	4492.1250
16 5/8	52.229	217.077	14.732	1.50	276.3906	4594.9941
16 3/4	52.621	220.353	14.843	1.53	280.5625	4699.4219
16 7/8	53.014	223.654	14.954	1.55	284.7656	4805.4199
17	53.407	226.980	15.065	1.57	289.	4913.
17 1/8	53.799	230.330	15.176	1.59	293.2656	5122.1738
17 1/4	54.192	233.705	15.286	1.62	297.5625	5132.9531
17 3/8	54.585	237.104	15.397	1.64	301.8906	5245.3496
17 1/2	54.978	240.528	15.508	1.66	306.25	5359.3750
17 5/8	55.370	243.977	15.619	1.69	310.6406	5475.0410
17 3/4	55.763	247.450	15.730	1.71	315.0625	5592.3594
17 7/8	56.156	250.947	15.840	1.74	319.3156	5711.3418
18	56.548	254.469	15.951	1.76	324.	5832.
18 1/8	56.941	258.016	16.062	1.79	328.5156	5954.3457
18 1/4	57.334	261.587	16.173	1.81	333.0625	6078.3906
18 3/8	57.726	265.182	16.283	1.83	337.6406	6204.1465
18 1/2	58.119	268.803	16.394	1.86	342.25	6331.6250
18 5/8	58.512	272.447	16.505	1.88	346.8906	6460.8379
18 3/4	58.905	276.117	16.616	1.91	351.5625	6591.7969
18 7/8	59.297	279.811	16.729	1.94	356.2656	6724.5137
19	59.690	283.529	16.837	1.96	361.	6859.
19 1/8	60.083	287.272	16.948	1.98	365.7656	6995.2636
19 1/4	60.475	291.039	17.060	2.02	370.5625	7132.3281
19 3/8	60.868	294.831	17.170	2.04	375.3906	7273.1934
19 1/2	61.261	298.648	17.280	2.07	380.25	7414.8750
19 5/8	61.653	302.489	17.391	2.10	385.1406	7558.3848
19 3/4	62.046	306.355	17.502	2.12	390.0625	7703.7344
19 7/8	62.439	310.245	17.613	2.15	395.0156	7850.9355
20	62.832	314.160	17.724	2.18	400.	8000.
20 1/8	63.224	318.099	17.834	2.21	405.0156	8150.9395
20 1/4	63.617	322.063	17.945	2.23	410.0625	8303.7656
20 3/8	64.010	326.051	18.056	2.26	415.1406	8458.8489
20 1/2	64.402	330.064	18.167	2.28	420.25	8615.1250
20 5/8	64.795	334.101	18.277	2.31	425.3906	8773.6816
20 3/4	65.188	338.163	18.388	2.34	430.5625	8934.1719
20 7/8	65.580	342.250	18.499	2.37	435.7565	9096.6074
21	65.793	346.361	18.610	2.40	441.	9261.
21 1/8	66.366	350.497	18.721	2.43	446.2656	9427.3613
21 1/4	66.759	354.657	18.831	2.46	451.5625	9595.7031
21 3/8	67.151	358.841	18.942	2.49	456.8906	9766.0371
21 1/2	67.544	363.051	19.053	2.52	462.25	9938.3750

TABLE XIX.—*Continued.*

Diameter in inches.	Circumference in inches.	Area in Sq. inches.	Sides of Equal Squares, inches.	Area in Sq. feet.	Square, in inches.	Cube, in inches.
21 1/8	67.937	367.284	19.164	2.55	467.6406	10112.7285
21 2/8	68.329	371.543	19.274	2.57	473.0625	10289.1094
21 3/8	68.772	375.826	19.385	2.59	478.5156	10467.5293
22	69.115	380.133	19.496	2.63	484.	10648.
22 1/8	69.507	384.465	19.607	2.66	489.5156	10830.5332
22 2/8	69.900	388.822	19.718	2.70	495.0625	11015.1406
22 3/8	70.293	393.203	19.828	2.73	500.6406	11201.8340
22 4/8	70.686	397.608	19.939	2.76	506.25	11390.6250
22 5/8	71.078	402.038	20.050	2.79	511.8906	11581.5254
22 6/8	71.471	406.493	20.161	2.82	517.5625	11774.5469
22 7/8	71.864	410.972	20.271	2.85	523.2656	11969.7012
23	72.256	415.476	20.382	2.88	529.	12167.
23 1/8	72.649	420.004	20.493	2.91	534.7656	12366.4551
23 2/8	73.042	424.557	20.604	2.94	540.5625	12568.0781
23 3/8	73.434	429.135	20.715	2.97	546.3906	12771.8809
23 4/8	73.827	433.731	20.825	3.01	552.25	12977.8750
23 5/8	74.220	438.363	20.936	3.04	558.1406	13185.986
23 6/8	74.613	443.014	21.047	3.07	564.0625	13396.4844
23 7/8	75.005	447.699	21.158	3.10	570.0156	13609.1230
24	75.398	452.390	21.268	3.14	576.	13824.
24 1/8	75.791	457.115	21.379	3.17	582.0156	14041.1270
24 2/8	76.183	461.864	21.490	3.20	588.0625	14260.5156
24 3/8	76.576	466.638	21.601	3.24	594.1406	14482.1777
24 4/8	76.969	471.436	21.712	3.27	600.25	14706.125
24 5/8	77.361	476.259	21.822	3.31	606.3906	14932.369
24 6/8	77.754	481.106	21.933	3.34	612.5625	15160.921
24 7/8	78.147	485.978	22.044	3.37	618.7656	15391.794
25	78.540	490.875	22.155	3.40	625.	15625.
25 1/8	78.932	495.796	22.265	3.44	631.2656	15860.548
25 2/8	79.325	500.741	22.376	3.47	637.5625	16098.453
25 3/8	79.718	505.711	22.487	3.51	643.8906	16338.323
25 4/8	80.110	510.706	22.598	3.54	650.25	16581.375
25 5/8	80.503	515.725	22.709	3.58	656.6406	16826.416
25 6/8	80.896	520.769	22.819	3.61	663.0625	17073.859
25 7/8	81.288	525.837	22.930	3.65	669.5156	17323.716
26	81.681	530.930	23.041	3.68	676.	17576.
26 1/8	82.074	536.047	23.152	3.72	682.5156	17830.7207
26 2/8	82.467	541.189	23.062	3.75	689.0625	18087.8906
26 3/8	82.859	546.356	23.373	3.79	695.6406	18347.5215
26 4/8	83.252	551.547	23.484	3.83	702.25	18609.625
26 5/8	83.645	556.762	23.595	3.87	708.8906	18874.2129
26 6/8	84.037	562.002	23.708	3.90	715.5625	19141.2969
26 7/8	84.430	567.267	23.816	3.94	722.265	19410.8887
27	84.823	572.556	23.927	3.97	729.	19683.

TABLE XIX.—*Continued.*

Diameter in inches.	Circumference in inches.	Area in Sq. inches.	Sides of Equal Squares, inches.	Area in Sq. feet.	Square, in inches.	Cube, in inches.
27 1/8	85.215	577.870	24.038	4.01	735.7565	19957.6426
27 1/4	85.608	583.208	24.149	4.05	742.5625	20234.8281
27 3/8	86.001	588.571	24.259	4.09	749.3906	20514.568
27 1/2	86.394	593.958	24.370	4.12	756.25	20796.875
27 5/8	86.786	599.370	24.481	4.16	763.1406	21081.7598
27 3/4	87.179	604.807	24.592	4.20	770.062	21369.234
27 7/8	87.572	610.268	24.703	4.24	777.0156	21659.3105
28	87.964	615.753	24.813	4.27	784.	21952.
28 1/8	88.357	621.263	24.924	4.31	791.0156	22427.3145
28 1/4	88.750	626.798	25.035	4.35	798.0625	22545.265
28 3/8	89.142	632.357	25.146	4.39	805.1406	22845.8652
28 1/2	89.535	637.941	25.256	4.43	812.25	23149.125
28 5/8	89.928	643.594	25.367	4.47	819.3906	23455.0566
28 3/4	90.321	649.182	25.478	4.50	826.5625	23763.6719
28 7/8	90.713	654.839	25.589	4.54	833.7656	24074.9824
29	91.106	660.521	25.699	4.58	841.	24389.
29 1/8	91.499	666.227	25.80	4.62	848.2656	24705.7363
29 1/4	91.891	671.958	25.921	4.66	855.5625	25025.2031
29 3/8	92.284	677.714	26.032	4.70	862.8906	25347.4121
29 1/2	92.677	683.494	26.143	4.74	870.25	25672.375
29 5/8	93.069	689.298	26.253	4.78	877.640	26000.1035
29 3/4	93.462	695.128	26.364	4.82	885.0625	26330.6094
29 7/8	93.855	700.981	26.478	4.86	892.5156	26663.9043
30	94.248	706.860	26.586	4.90	900.	27000.
30 1/8	94.640	712.762	26.696	4.95	907.5156	27338.908
30 1/4	95.033	718.690	26.807	4.99	915.0625	27689.6406
30 3/8	95.426	724.641	26.918	5.03	922.6406	28028.2090
30 1/2	95.818	730.618	27.029	5.07	930.25	28372.625
30 5/8	96.211	736.619	27.139	5.11	937.8906	28722.8004
30 3/4	96.604	742.644	27.250	5.15	945.5626	29076.046
30 7/8	96.996	748.694	27.361	5.19	953.2656	29432.076
31	97.389	754.769	27.472	5.24	961.	29791.
31 1/8	97.782	760.868	27.583	5.28	968.7656	30152.8301
31 1/4	98.175	766.992	27.693	5.32	976.5625	30517.5781
31 3/8	98.567	773.140	27.803	5.37	984.3906	30885.2559
31 1/2	98.968	779.313	27.915	5.41	992.25	31255.875
31 5/8	99.353	785.510	28.026	5.45	1000.1406	31629.447
31 3/4	99.745	791.732	28.136	5.49	1008.0625	32005.984
31 7/8	100.138	797.978	28.247	5.53	1016.0156	32385.498
32	100.531	804.249	28.358	5.58	1024.	32768.
32 1/8	100.924	810.545	28.469	5.62	1032.0156	33153.5020
32 1/4	101.316	816.865	28.580	5.67	1040.0625	33542.0156
32 3/8	101.709	823.209	28.691	5.71	1048.846	33956.314
32 1/2	102.102	829.578	28.801	5.75	1056.25	34328.125

TABLE XIX.—*Continued.*

Diameter in inches.	Circumference in inches.	Area in Sq. inches.	Sides of Equal Squares, inches.	Area in Sq. feet.	Square, in inches.	Cube, in inches.
32⅝	102.494	835.972	28.912	5.79	1064.3906	34725.743
32¾	102.887	842.390	29.023	5.84	1072.5625	35026.422
32⅞	103.280	848.833	29.133	5.89	1080.7656	35530.169
33	103.672	855.30	29.244	5.93	1089.	35937.
33⅛	104.055	861.79	29.355	5.98	1097.2656	36346.923
33¼	104.458	868.30	29.466	6.03	1105.5625	36759.953
33⅜	104.850	874.84	29.577	6.08	1113.8906	37176.099
33½	105.243	881.41	29.687	6.12	1122.25	37595.375
33⅝	105.636	888.00	29.798	6.17	1130.6406	38071.799
33¾	106.029	894.61	29.909	6.21	1139.0625	38443.359
33⅞	106.421	901.25	30.020	6.26	1147.5156	38872.091
34	106.814	907.92	30.131	6.30	1156.	39304.
34⅛	107.207	914.61	30.241	6.35	1164.5156	39739.095
34¼	107.599	921.32	30.352	6.39	1173.0625	40177.390
34⅜	107.992	928.06	30.463	6.44	1181.6406	40618.896
34½	108.385	934.82	30.574	6.49	1190.25	41063.625
34⅝	108.777	941.60	30.684	6.54	1198.8906	41511.588
34¾	109.170	948.41	30.795	6.58	1207.5625	41962.797
34⅞	109.563	955.25	30.906	6.63	1216.2656	42417.263
35	109.956	962.11	31.017	6.68	1225.	42875.
35⅛	110.348	968.99	31.128	6.73	1233.7656	43336.0176
35¼	110.741	975.90	31.238	6.77	1242.5625	43800.3281
35⅜	111.134	982.84	31.349	6.82	1251.3906	44267.943
35½	111.526	989.80	31.460	6.87	1260.25	44738.875
35⅝	111.919	996.78	31.571	6.92	1269.1406	45123.134
35¾	112.312	1003.78	31.681	6.97	1278.0625	45690.734
35⅞	112.704	1010.83	31.791	7.02	1287.0156	46171.685
36	113.097	1017.87	31.903	7.06	1296.	46656.
36⅛	113.490	1024.95	32.014	7.11	1308.0156	47252.063
36¼	113.883	1032.06	32.124	7.16	1314.0625	47634.765
36⅜	114.275	1039.19	32.235	7.21	1323.1406	48129.240
36½	114.668	1046.39	32.346	7.26	1332.25	48627.125
36⅝	115.061	1053.52	32.457	7.31	1341.3906	49128.130
36¾	115.453	1060.73	32.567	7.36	1350.5625	49633.172
36⅞	115.846	1067.95	32.678	7.41	1359.7656	50141.3574
37	116.239	1075.21	32.789	7.46	1369.	50653.
37⅛	116.631	1082.48	32.900	7.51	1378.2656	51168.1113
37¼	117.024	1089.79	33.011	7.56	1387.5625	51686.703
37⅜	117.417	1097.11	33.021	7.61	1396.8906	52208.7871
37½	117.810	1104.46	33.232	7.66	1406.25	52734.375
37⅝	118.202	1111.84	33.343	7.72	1415.6406	53263.478
37¾	118.595	1119.24	33.454	7.77	1425.0625	53796.109
37⅞	118.988	1126.66	33.564	7.82	1434.5056	54332.279
38	119.380	1134.11	33.675	7.87	1444.	54872.

TABLE XIX.—*Continued.*

Diameter in inches.	Circumference in inches.	Area in Sq. inches.	Sides of Equal Squares, inches.	Area in Sq. feet.	Square, in inches.	Cube, in inches.
38⅛	119.773	1141.59	33.786	7.92	1453.5156	55415.283
38¼	120.166	1149.08	33.897	7.97	1463.0625	55962.1406
38⅜	120.558	1156.61	34.008	8.02	1472.6406	56512.584
38½	120.951	1164.15	34.118	8.08	1482.25	57066.625
38⅝	121.344	1171.73	34.229	8.14	1491.8906	57624.275
38¾	121.737	1179.32	34.340	8.19	1501.5625	58185.547
38⅞	122.129	1186.94	34.451	8.24	1511.2656	58751.4512
39	122.522	1194.59	34.561	8.29	1521.	59319.
39⅛	122.915	1202.26	34.672	8.34	1530.7656	59891.2051
39¼	123.307	1209.95	34.783	8.40	1540.5625	60466.0781
39⅜	123.700	1217.67	34.894	8.45	1550.3906	61046.6309
39½	124.093	1225.42	35.005	8.50	1560.25	61629.875
39⅝	124.485	1233.18	35.115	8.56	1570.1406	62216.8223
39¾	124.878	1240.98	35.226	8.61	1580.0625	62807.484
39⅞	125.271	1248.79	35.337	8.67	1590.0156	63401.873
40	125.664	1256.64	35.448	8.72	1600.	64000.
40⅛	126.056	1264.50	35.558	8.78	1610.0156	64601.877
40¼	126.449	1272.39	35.669	8.83	1620.0625	65207.5156
40⅜	126.842	1280.31	35.780	8.89	1630.1406	65816.927
40½	127.234	1288.25	35.891	8.94	1640.25	66430.125
40⅝	127.627	1296.21	36.002	9.00	1650.3906	67047.110
40¾	128.020	1304.20	36.112	9.05	1660.5625	67667.922
40⅞	128.412	1312.21	36.223	9.11	1670.7656	68292.545
41	128.805	1320.25	36.334	9.16	1681.	68921.
41⅛	129.198	1328.32	36.445	9.22	1691.2656	69553.298
41¼	129.591	1336.40	36.555	9.28	1701.5625	70189.453
41⅜	129.983	1344.51	36.666	9.34	1711.8906	70829.474
41½	130.376	1352.65	36.777	9.39	1722.25	71473.375
41⅝	130.769	1360.81	36.881	9.45	1732.6406	72121.1660
41¾	131.161	1369.00	36.999	9.50	1743.0625	72772.859
41⅞	131.554	1377.21	37.109	9.56	1753.5156	73428.466
42	131.947	1385.44	37.220	9.62	1764.	74088.
42⅛	132.339	1393.70	37.331	9.67	1774.5156	74751.4707
42¼	132.732	1401.98	37.442	9.72	1785.0625	75418.8906
42⅜	133.125	1410.29	37.552	9.77	1795.6406	76090.2715
42½	133.518	1418.62	37.663	9.82	1806.25	76765.625
42⅝	133.910	1426.98	37.774	9.89	1816.8906	77444.963
42¾	134.303	1435.36	37.885	9.95	1827.5625	78128.297
42⅞	134.696	1443.77	37.996	10.02	1838.2656	78815.638
43	135.088	1452.20	38.106	10.08	1849.	79507.
43⅛	135.481	1460.65	38.217	10.14	1859.7656	80202.3926
43¼	135.874	1469.13	38.328	10.20	1870.5625	80901.8281
43⅜	136.266	1477.63	38.439	10.26	1881.3906	81605.3183
43½	136.659	1486.17	38.549	10.32	1892.25	82313.875

TABLE XIX.—*Continued.*

Diameter in inches.	Circumference in inches.	Area in Sq. inches.	Sides of Equal Squares, inches.	Area in Sq. feet.	Square, in inches.	Cube, in inches.
43 5/8	137.052	1494.72	38.660	10.38	1903.1406	83024.5097
43 3/4	137.445	1503.30	38.771	10.44	1914.1625	83740.234
43 7/8	137.837	1511.90	38.882	10.50	1925.0156	84460.0605
44	138.230	1520.53	38.993	10.55	1936.	85184.
44 1/8	138.623	1529.18	39.103	10.61	1947.0156	85912.0644
44 1/4	139.015	1537.86	39.214	10.67	1958.0625	86644.2656
44 3/8	139.408	1546.55	39.325	10.74	1969.1406	87380.6152
44 1/2	139.801	1555.28	39.436	10.80	1980.25	88121.125
44 5/8	140.193	1564.03	39.546	10.86	1991.3906	88865.8066
44 3/4	140.586	1572.81	39.657	10.92	2002.5625	89614.6719
44 7/8	140.979	1581.61	39.768	10.98	2013.7656	90367.7324
45	141.372	1590.43	39.879	11.04	2025.	91125.
45 1/8	141.764	1599.28	39.989	11.11	2036.2656	91886.4863
45 1/4	142.157	1608.15	40.110	11.16	2047.5625	92652.2031
45 3/8	142.550	1617.04	40.211	11.22	2058.8906	93422.1621
45 1/2	142.942	1625.97	40.322	11.27	2070.25	94196.375
45 5/8	143.335	1634.92	40.432	11.34	2081.6406	94974.853
45 3/4	143.728	1643.89	40.543	11.41	2093.0625	95757.6094
45 7/8	144.120	1652.88	40.654	11.48	2104.5156	96544.654
46	144.513	1661.90	40.765	11.54	2116.	97336.
46 1/8	144.906	1670.95	40.876	11.61	2127.5156	98131.6582
46 1/4	145.299	1680.01	40.986	11.67	2139.0625	98931.640
46 3/8	145.691	1689.10	41.097	11.73	2150.6406	99735.959
46 1/2	146.084	1698.23	41.208	11.79	2162.25	100544.625
46 5/8	146.477	1707.37	41.319	11.86	2171.8906	101357.650
46 3/4	146.869	1716.54	41.429	11.92	2185.5625	102175.047
46 7/8	147.262	1725.73	41.540	11.98	2197.2656	102996.826
47	147.655	1734.94	41.651	12.04	2209.	103823.
47 1/8	148.047	1744.18	41.762	12.11	2220.7656	104653.58
47 1/4	148.440	1753.45	41.873	12.17	2232.5625	105488.578
47 3/8	148.833	1762.73	41.983	12.24	2244.3906	106328.005
47 1/2	149.226	1772.05	42.094	12.30	2256.25	107171.875
47 5/8	149.618	1781.39	42.205	12.37	2268.1406	108020.197
47 3/4	150.011	1790.76	42.316	12.43	2280.0625	108872.984
47 7/8	150.404	1800.14	42.427	12.50	2292.0156	109730.248
48	150.796	1809.56	42.537	12.56	2304.	110592.
48 1/8	151.189	1818.99	42.648	12.63	2316.0156	111458.2520
48 1/4	151.582	1828.46	42.759	12.69	2328.0625	112329.0156
48 3/8	151.974	1837.93	42.870	12.76	2340.1406	113204.3027
48 1/2	152.367	1847.45	42.980	12.82	2352.25	114084.125
48 5/8	152.760	1856.99	43.091	12.89	2364.3906	114968.494
48 3/4	153.153	1866.55	43.202	12.96	2376.5625	115857.422
48 7/8	153.545	1876.13	43.313	13.02	2388.7666	116750.919
49	153.938	1885.74	43.423	13.09	2401.	117649.

TABLE XIX.—*Continued.*

Diameter in inches.	Circumference in inches.	Area in Sq. inches.	Sides of Equal Squares, inches.	Area in Sq. feet.	Square, in inches.	Cube, in inches.
49⅛	154.331	1895.37	43.534	13.16	2413.2656	118551.6738
49¼	154.723	1905.03	43.645	13.23	2425.5625	119458.9531
49⅜	155.116	1914.70	43.756	13.30	2437.8906	120370.549
49½	155.509	1924.42	43.867	13.36	2450.25	121287.375
49⅝	155.901	1934.15	43.977	13.43	2462.640	122208.541
49¾	156.294	1943.91	44.088	13.50	2475.062	123134.359
49⅞	156.687	1953.69	44.199	13.57	2487.515	124064.336
50	157.080	1963.50	44.310	13.63	2500.	125000.
50¼	157.865	1983.18	44.531	13.77	2525.0625	126884.39
50½	158.650	2002.96	44.753	13.91	2550.25	127888.62
50¾	159.436	2022.84	44.974	14.05	2575.56	130701.79
51	160.221	2042.82	45.196	14.18	2601.	132651.
51¼	161.007	2062.90	45.417	14.32	2626.562	134611.328
51½	161.792	2083.07	45.639	14.46	2652.25	136590.87
51¾	162.577	2103.35	45.861	14.60	2678.062	138589.73
52	163.363	2123.72	46.082	14.74	2704.	140608.
52¼	164.148	2144.19	46.304	14.89	2730.062	142645.76
52½	164.934	2164.75	46.525	15.03	2756.25	144703.12
52¾	165.719	2185.42	46.747	15.18	2782.562	146780.17
53	166.504	2206.18	46.968	15.32	2809.	148877.
53¼	167.290	2227.05	47.190	15.47	2835.562	150993.70
53½	168.075	2248.01	47.411	15.61	2862.25	153130.37
53¾	168.861	2269.06	47.633	15.76	2889.062	155287.10
54	169.646	2290.22	47.854	15.90	2916.	157464.
54¼	170.431	2311.48	48.076	16.05	2943.062	159661.140
54½	171.217	2332.83	48.298	16.20	2970.25	161878.625
54¾	172.002	2354.28	48.519	16.35	2997.562	164116.546
55	172.788	2375.83	48.741	16.49	3025.	166375.
55¼	173.573	2397.48	48.964	16.65	3052.562	168654.078
55½	174.358	2419.22	49.185	16.80	3080.25	170953.87
55¾	175.144	2441.07	49.407	16.95	3094.140	172111.572
56	175.929	2463.01	49.628	17.10	3136.	175616.
56¼	176.715	2485.05	49.850	17.26	3164.062	177978.515
56½	177.500	2507.19	50.070	17.41	3192.25	180362.125
56¾	178.285	2529.42	50.291	17.57	3220.562	182766.92
57	179.071	2551.76	50.513	17.72	3249.	185193.
57¼	179.856	2574.19	50.735	17.88	3277.562	187640.45
57½	180.642	2596.72	50.956	18.03	3306.25	190109.37
57¾	181.427	2619.35	51.178	18.19	3335.062	192599.85
58	182.212	2642.08	51.399	18.34	3364.	195112.
58¼	182.998	2664.91	51.621	18.50	3393.062	197645.89
58½	183.783	2687.83	51.842	18.66	3422.25	200201.62
58¾	184.569	2710.85	52.064	18.82	3451.56	202779.29
59	185.354	2733.97	52.285	18.98	3481.	205379.

TABLE XIX.—*Continued.*

Diameter in inches.	Circumference in inches.	Area in Sq. inches.	Sides of Equal Squares, inches.	Area in Sq. feet.	Square, in inches.	Cube, in inches.
59¼	186.139	2757.19	52.507	19.14	3510.56	208000.82
59½	186.925	2780.51	52.729	19.30	3540.25	210644.87
59¾	187.710	2803.92	52.950	19.47	3570.062	213311.23
60	188.496	2829.44	53.172	19.63	3600.	216000.
60¼	189.281	2851.05	53.393	19.80	3630.062	218711.26
60½	190.666	2874.76	53.615	19.96	3660.25	221445.12
60¾	190.852	2898.56	53.836	20.13	3690.56	224201.67
61	191.637	2922.47	54.048	20.29	3721.	226981.
61¼	192.423	2946.47	54.279	20.47	3751.562	229783.20
61½	193.208	2970.57	54.501	20.63	3782.25	232608.37
61¾	193.993	2994.77	54.723	20.80	3813.062	235456.60
62	194.779	3019.07	54.944	20.96	3844.	238328.
62¼	195.564	3043.47	55.166	21.13	3875.062	241222.64
62½	196.350	3067.96	55.387	21.30	3906.25	244140.62
62¾	197.135	3092.56	55.609	21.47	3937.562	247082.04
63	197.920	3117.25	55.830	21.64	3969.	250047.
63¼	198.706	3142.04	56.052	21.82	4000.562	253035.57
63½	199.491	3166.92	56.273	21.99	4032.25	256047.87
63¾	200.277	3191.91	56.495	22.17	4064.06	259083.98
64	201.062	3216.99	56.716	22.34	4096.	262144.
64¼	201.847	3242.17	56.938	22.52	4128.062	265228.01
64½	202.633	3267.46	57.159	22.69	4160.25	268336.12
64¾	203.418	3292.83	57.381	22.87	4192.56	271468.42
65	204.204	3318.31	57.603	23.04	4225.	274625.
65¼	204.989	3343.88	57.824	23.22	4257.56	277805.95
65½	205.774	3369.56	58.046	23.40	4290.25	281011.37
65¾	206.560	3395.33	58.267	23.58	4323.06	284241.35
66	207.345	3421.20	58.489	23.75	4356.	287496.
66¼	208.131	3447.16	58.710	23.94	4389.062	290775.39
66½	208.916	3473.23	58.932	24.12	4422.25	294079.62
66¾	209.701	3499.39	59.154	24.30	4455.56	297408.79
67	210.487	3525.66	59.375	24.48	4489.	300763.
67¼	211.272	3552.01	59.597	24.67	4522.56	304142.32
67½	212.058	3578.47	59.818	24.85	4556.25	307546.87
67¾	212.843	3605.03	60.040	25.03	4590.062	310976.73
68	213.628	3631.68	60.261	25.21	4624.	314432.
68¼	214.414	3658.44	60.483	25.40	4658.06	317912.76
68½	215.199	3685.29	60.704	25.59	4692.25	321419.12
68¾	215.985	3712.24	60.926	25.78	4726.56	324951.47
69	216.770	3739.28	61.147	25.96	4761.	328509.
69¼	217.555	3766.43	61.369	26.15	4795.562	332092.70
69½	218.341	3793.67	61.691	26.34	4830.25	335702.37
69¾	219.126	3821.02	61.812	26.53	4865.06	339338.10
70	219.912	3848.46	62.034	26.72	4900.	343000.

TABLE XIX.—*Continued.*

Diameter in inches.	Circumference in inches.	Area in Sq. inches.	Sides of Equal Squares, inches.	Area in Sq. feet.	Square, in inches.	Cube, in inches.
70¼	220.697	3875.99	62.255	26.92	4935.062	346688.14
70½	221.482	3903.63	62.477	27.11	4970.25	350402.62
70¾	222.268	3931.36	62.698	27.30	5005.56	354413.54
71	223.053	3959.20	62.920	27.49	5041.	357911.
71¼	223.835	3987.13	63.141	27.69	5076.562	361705.07
71½	224.624	4015.16	63.363	27.88	5112.25	365525.87
71¾	225.409	4043.28	63.545	28.08	5148.06	369373.48
72	226.195	4071.51	63.806	28.27	5184.	373248.
72¼	226.980	4099.83	64.028	28.47	5220.06	377149.51
72½	227.766	4128.25	64.249	28.67	5256.25	381078.12
72¾	228.551	4156.77	64.471	28.87	5274.390	383052.61
73	229.336	4185.39	64.692	29.06	5329.	389017.
73¼	230.122	4214.11	64.914	29.26	5365.56	393027.45
73½	230.907	4242.92	65.135	29.46	5402.25	397065.37
73¾	231.693	4271.83	65.357	29.66	5439.06	401130.85
74	232.478	4300.85	65.578	29.86	5476.	405224.
74¼	233.263	4329.95	65.800	30.06	5513.0625	409344.890
74½	234.049	4359.16	66.022	30.27	5550.25	413493.62
74¾	234.834	4388.47	66.243	30.47	5587.562	417670.29
75	235.620	4417.87	66.465	30.67	5625.	421875.
75¼	236.405	4447.37	66.686	30.88	5662.5625	426107.82
75½	237.190	4476.97	66.908	31.09	5700.25	430368.87
75¾	237.976	4506.67	67.129	31.30	5738.0625	434658.23
76	238.761	4536.47	67.351	31.50	5776.	438976.
76¼	239.547	4566.36	67.572	31.71	5814.0625	443322.265
76½	240.332	4596.35	67.794	31.92	5852.25	447697.125
76¾	241.117	4626.44	68.016	32.13	5890.5625	452100.672
77	241.903	4656.63	68.237	32.33	5929.	456533.
77¼	242.688	4686.92	68.459	32.55	5967.562	460994.20
77½	243.474	4717.30	68.680	32.76	6006.25	465484.37
77¾	244.259	4747.79	68.902	32.97	6045.0625	470003.609
78	245.044	4778.37	69.123	33.18	6064.5156	472274.15
78¼	245.830	4809.05	69.345	33.40	6123.0625	479129.64
78½	246.615	4839.83	69.566	33.62	6162.25	483736.62
78¾	247.401	4870.70	69.788	33.83	6201.5625	488373.046
79	248.186	4901.68	70.009	34.03	6241.	493039.
79¼	248.971	4932.75	70.231	34.25	6280.5625	497734.57
79½	249.757	4963.92	70.453	34.47	6320.25	502509.875
79¾	250.542	4995.19	70.674	34.69	6360.0625	507214.98
80	251.328	5026.56	70.896	34.90	6400.	512000.
80¼	252.113	5058.02	71.117	35.12	6440.0625	516815.015
80½	252.898	5089.58	71.339	35.34	6480.25	521660.125
80¾	253.684	5121.24	71.560	35.56	6520.5625	526535.42
81	254.469	5153.00	71.782	35.67	6561.	531441.

TABLE XIX.—*Continued.*

Diameter in inches	Circumference in inches.	Area in Sq. inches.	Sides of Equal Squares, inches.	Area in Sq. feet.	Square, in inches.	Cube, in inches.
81¼	255.255	5184.86	72.003	35.90	6601.562	536376.95
81½	256.040	5216.82	72.225	36.12	6642.25	541343.37
81¾	256.825	5248.87	72.446	36.34	6683.0625	546340.36
82	257.611	5281.02	72.668	36.56	6724.	551368.
82¼	258.396	5313.27	72.880	36.89	6765.062	556426.39
82½	259.182	5345.62	73.111	37.10	6806.25	561515.62
82¾	259.967	5378.07	73.333	37.34	6847.56	566635.79
83	260.752	5410.62	73.554	37.57	6889.	571787.
83¼	261.538	5443.26	73.761	37.80	6930.562	576969.32
83½	262.323	5476.00	73.997	38.03	6972.25	582182.87
83¾	263.109	5508.84	74.219	38.26	7014.062	587427.73
84	263.894	5541.78	74.440	38.48	7056.	592304.
84¼	264.679	5574.81	74.662	38.72	7098.0625	598011.7656
84½	265.465	5607.95	74.884	38.94	7140.25	603351.125
84¾	266.250	5641.18	75.105	39.17	7182.5625	608722.171
85	267.036	5674.51	75.327	39.40	7225.	614125.
85¼	267.821	5707.94	75.548	39.66	7267.562	619559.70
85½	268.606	5741.47	75.770	39.92	7310.25	625026.37
85¾	269.392	5775.09	75.991	40.13	7353.062	630525.109
86	270.177	5808.81	76.213	40.33	7396.	636056.
86¼	270.963	5842.63	76.434	40.57	7439.062	641619.140
86½	271.748	5876.55	76.656	40.81	7482.25	647214.62
86¾	272.533	5910.57	76.877	41.05	7525.56	652842.54
87	273.319	5944.69	77.099	41.28	7569.	658503.
87¼	274.104	5978.88	77.321	41.53	7612.5625	664196.07
87½	274.890	6013.21	77.542	41.76	7656.25	669921.87
87¾	275.675	6047.62	77.764	42.00	7700.062	675680.48
88	276.460	6082.13	77.985	42.23	7744.	681472.
88¼	277.246	6116.74	78.207	42.48	7788.062	687296.51
88½	278.031	6151.44	78.428	42.72	7832.25	693154.12
88¾	278.817	6186.25	78.650	42.96	7876.56	699044.92
89	279.602	6221.15	78.871	43.20	7921.	704969.
89¼	280.387	6256.15	79.093	43.44	7965.56	710926.45
89½	281.173	6291.25	79.315	43.68	8010.25	716917.37
89¾	281.958	6326.44	79.536	43.93	8055.062	723051.85
90	282.744	6361.74	79.758	44.17	8100.	729000.
90¼	283.529	6399.13	79.979	44.42	8145.062	735091.89
90½	284.314	6432.62	80.201	44.67	8190.25	741217.62
90¾	285.100	6468.16	80.422	44.92	8235.56	747377.29
91	285.885	6503.89	80.644	45.16	8281.	753571.
91¼	286.671	6539.68	80.865	45.41	8326.56	759798.82
91½	287.456	6573.56	81.087	45.66	8372.25	766060.87
91¾	288.241	6611.54	81.308	45.91	8418.06	772357.23
92	289.027	6647.62	81.530	46.16	8464.	778688.

TABLE XIX.—*Continued.*

Diameter in inches.	Circumference in inches.	Area in Sq. inches.	Sides of Equal Squares, inches.	Area in Sq. feet.	Square, in inches.	Cube, in inches.
92¼	289.812	6683.80	81.751	46.42	8510.062	785053.26
92½	290.598	6720.07	81.973	46.67	8556.26	791453.12
92¾	291.383	6756.45	82.195	46.92	8602.56	797887.67
93	292.168	6792.92	82.416	47.17	8649.	804357.
93¼	292.954	6829.49	82.638	47.43	8695.56	810861.20
93½	293.739	6866.16	82.859	47.68	8742.25	817400.37
93¾	294.525	6902.92	83.081	47.94	8789.06	823974.60
94	295.310	6939.79	83.302	48.19	8836.	830584.
94¼	296.095	6976.75	83.524	48.45	8883.0625	837228.64
94½	296.881	7013.81	83.746	48.71	8930.25	843908.62
94¾	297.666	7050.97	83.964	48.97	8977.562	850624.04
95	298.452	7088.23	84.189	49.22	9025.	857375.
95¼	299.237	7125.58	84.410	49.48	9072.5625	864161.57
95½	300.022	7163.04	84.632	49.74	9120.25	870983.87
95¾	300.808	7200.59	84.853	50.00	9168.062	877841.98
96	301.593	7238.24	85.075	50.26	9216.	884736.
96¼	302.379	7275.99	85.296	50.53	9264.0625	891666.01
96½	303.164	7313.84	85.518	50.79	9312.25	898632.12
96¾	303.949	7351.78	85.739	51.05	9360.562	905634.4
97	304.735	7389.82	85.961	51.31	9409.	912673.
97¼	305.520	7427.96	86.183	51.58	9457.562	919747.95
97½	306.306	7466.20	86.404	51.85	9506.25	926859.37
97¾	307.091	7504.54	86.626	52.12	9555.062	934007.35
98	307.876	7542.98	86.847	52.38	9604.	941192.
98¼	308.662	7581.51	87.069	52.65	9653.062	948413.39
98½	309.447	7620.14	87.290	52.92	9702.25	955671.62
98¾	310.233	7658.87	87.512	53.19	9751.56	962966.79
99	311.018	7697.70	87.733	53.45	9801.	970299.
99¼	311.803	7736.62	87.955	53.73	9850.56	977688.32
99½	312.589	7775.65	88.176	54.00	9900.25	985074.87
99¾	313.374	7814.77	88.398	54.27	9950.062	992518.73
100	314.160	7854.00	88.620	54.54	10000.	1000000.

Table XX.

Standard Sheet and Hoop Iron Gauge (B.G.),

Issued in March 1884, *by the South Staffordshire Ironmasters' Association, for the use of Sheet and Hoop Iron Makers.*

No. of Gauge.	Thickness in			Approximate Weight per superficial foot of Sheet Iron in lbs.
	Ordinary Fractions of an Inch.	Decimals of an Inch.	Millimetres.	
3°	½	.5000	12.700	20.000
2°	...	.4452	11.288	17.808
1°	...	.3964	10.068	15.856
1	...	.3532	8.971	14.128
2	...	.3147	7.993	12.588
3	...	.2804	7.122	11.216
4	¼	.2500	6.350	10.000
5	...	.2225	5.651	8.900
6	..	.1981	5.032	7.924
7	...	.1764	4.480	7.056
8	...	.1570	3.988	6.280
9	...	.1398	3.551	5.592
10	⅛	.1250	3.175	5.000
11	...	.1113	2.827	4.452
12	...	.0991	2.517	3.964
13	...	.0882	2.240	3.528
14	...	.0785	1.994	3.140
15	...	.0699	1.775	2.796
16	1/10	.0625	1.587	2.500
17	...	.0556	1.412	2.224
18	...	.0495	1.257	1.980
19	...	.0440	1.118	1.760
20	...	.0392	.996	1.568
21	...	.0349	.886	1.396
22	1/32	.03125	.794	1.250
23	...	.02782	.707	1.1128
24	...	.02476	.629	.9904
25	...	.02204	.560	.8816
26	...	.01961	.498	.7844
27	...	.01745	.4432	.698
28	1/64	.015625	.3969	.625
29	...	.01390	.3531	.556
30	...	.0123	.3124	.492
31	...	.0110	.2794	.440
32	...	.0098	.2489	.392
33	...	.0087	.2210	.348
34	...	.0077	.1956	.300

TABLE XX.—*Continued.*

No. of Gauge.	Thickness in			Approximate Weight per superficial foot of Sheet Iron in lbs.
	Ordinary Fractions of an Inch.	Decimals of an Inch.	Millimetres.	
35	...	.0069	.1753	.276
36	...	.0061	.1549	.244
37	...	.0054	.1371	.216
38	...	.0048	.1219	.192
39	...	.0043	.1092	.172
40	...	.00386	.0980	.1544

NOTE.—The weight in Steel can be found by adding 2 per cent., or $\frac{1}{50}$th, to the weight in Iron.

TABLE XXI.

WEIGHT OF IRON, STEEL, AND COPPER PLATES, 12 in. × 12 in., FROM $\frac{1}{4}$ in. TO $1\frac{1}{2}$ in. THICK.

Thickness.	Sectional Area.	Wrought Iron. Lbs.	Steel. Lbs.	Copper. Lbs.
$\frac{1}{4}$	3.00	10.0	10.2	11.5
$\frac{5}{16}$	3.75	12.5	12.75	14.37
$\frac{3}{8}$	4.50	15.0	15.3	17.24
$\frac{7}{16}$	5.20	17.5	17.85	20.12
$\frac{1}{2}$	6.00	20.0	20.4	23.0
$\frac{9}{16}$	6.75	22.5	22.95	25.87
$\frac{5}{8}$	7.50	25.0	25.5	28.74
$\frac{11}{16}$	8.25	27.5	28.05	31.62
$\frac{3}{4}$	9.00	30.0	30.6	34.48
$\frac{13}{16}$	9.75	32.5	33.15	37.37
$\frac{7}{8}$	10.50	35.0	35.7	40.24
$\frac{15}{16}$	11.25	37.5	38.25	43.12
1	12.00	40.0	40.8	46.0
$1\frac{1}{16}$	12.75	42.5	43.35	48.87
$1\frac{1}{8}$	13.50	45.0	45.90	51.75
$1\frac{3}{16}$	14.25	47.5	48.45	54.62
$1\frac{1}{4}$	15.0	50.0	51.0	57.48
$1\frac{5}{16}$	15.75	52.5	53.55	60.37
$1\frac{3}{8}$	16.5	55.0	56.10	63.24
$1\frac{7}{16}$	17.25	57.5	58.65	66.12
$1\frac{1}{2}$	18.0	60.0	61.2	68.96

TABLE XXII.

WEIGHT OF FLAT BAR IRON AND STEEL IN LBS. PER LINEAL FOOT.

Size (inches).	Sectional Area (square inches).	Weight (Iron).	Weight (Steel).
1 × 1/4	.250	.84	.85
1 × 3/8	.375	1.26	1.28
1 × 1/2	.500	1.69	1.70
1 × 5/8	.625	2.11	2.13
1 × 3/4	.750	2.53	2.55
1 × 7/8	.875	2.96	2.98
1 × 1	1.000	3.34	3.40
1 1/4 × 1/4	.313	1.05	1.06
1 1/4 × 3/8	.469	1.58	1.59
1 1/4 × 1/2	.625	2.11	2.13
1 1/4 × 5/8	.781	2.64	2.66
1 1/4 × 3/4	.938	3.16	3.19
1 1/4 × 7/8	1.11	3.70	3.72
1 1/4 × 1	1.25	4.22	4.25
1 3/8 × 1/4	.344	1.16	1.17
1 3/8 × 3/8	.516	1.74	1.75
1 3/8 × 1/2	.688	2.29	2.34
1 3/8 × 5/8	.859	2.87	2.92
1 3/8 × 3/4	1.03	3.44	3.51
1 3/8 × 7/8	1.20	4.01	4.09
1 3/8 × 1	1.38	4.59	4.68
1 1/2 × 1/4	.275	1.25	1.28
1 1/2 × 3/8	.563	1.87	1.91
1 1/2 × 1/2	.750	2.50	2.55
1 1/2 × 5/8	.938	3.13	3.19
1 1/2 × 3/4	1.13	3.75	3.83
1 1/2 × 7/8	1.31	4.38	4.46
1 1/2 × 1	1.50	5.00	5.10
1 3/4 × 1/4	.638	1.46	1.49
1 3/4 × 3/8	.656	2.19	2.23
1 3/4 × 1/2	.875	2.92	2.98
1 3/4 × 5/8	1.09	3.65	3.72
1 3/4 × 3/4	1.31	4.38	4.46
1 3/4 × 7/8	1.53	5.10	5.21
1 3/4 × 1	1.75	5.83	5.95
2 × 1/4	.500	1.67	1.70
2 × 3/8	.750	2.50	2.55
2 × 1/2	1.00	3.33	3.40
2 × 5/8	1.25	4.17	4.25
2 × 3/4	1.50	5.00	5.10
2 × 7/8	1.75	5.83	5.95
2 × 1	2.00	6.67	6.80

TABLE XXII.—*Continued.*

Size (inches).	Sectional Area (square inches).	Weight (Iron).	Weight (Steel).
2¼ × ¼	.563	1.88	1.91
2¼ × ⅝	.844	2.81	2.87
2¼ × ½	1.13	3.75	3.83
2¼ × ⅝	1.41	4.69	4.78
2¼ × ¾	1.69	5.63	5.74
2¼ × ⅞	1.97	6.56	6.69
2¼ × 1	2.25	7.50	7.65
2½ × ¼	.625	2.08	2.13
2½ × ⅜	.938	3.13	3.19
2½ × ½	1.25	4.17	4.25
2½ × ⅝	1.56	5.21	5.31
2½ × ¾	1.88	6.25	6.38
2½ × ⅞	2.19	7.29	7.44
2½ × 1	2.50	8.33	8.50
2¾ × ¼	.688	2.29	2.34
2¾ × ⅜	1.03	3.44	3.51
2¾ × ½	1.38	4.58	4.68
2¾ × ⅝	1.72	5.73	5.84
2¾ × ¾	2.06	6.88	7.01
2¾ × ⅞	2.41	8.02	8.18
2¾ × 1	2.75	9.17	9.35
3 × ¼	.750	2.50	2.55
3 × ⅜	1.13	3.75	3.83
3 × ½	1.50	5.00	5.10
3 × ⅝	1.88	6.25	6.38
3 × ¾	2.25	7.50	7.65
3 × ⅞	2.63	8.75	8.93
3 × 1	3.00	10.0	10.20
3¼ × ¼	.813	2.71	2.76
3¼ × ⅜	1.22	4.06	4.14
3¼ × ½	1.63	5.42	5.53
3¼ × ⅝	2.03	6.77	6.91
3¼ × ¾	2.44	8.13	8.29
3¼ × ⅞	2.84	9.48	9.67
3¼ × 1	3.25	10.8	11.05
3½ × ¼	.875	2.92	2.98
3½ × ⅜	1.31	4.38	4.46
3½ × ½	1.75	5.83	5.95
3½ × ⅝	2.19	7.29	7.44
3½ × ¾	2.63	8.75	8.93
3½ × ⅞	3.06	10.2	10.41
3½ × 1	3.50	11.7	11.90
3¾ × ¼	.938	3.13	3.19
3¾ × ⅜	1.41	4.69	4.78

TABLE XXII.—*Continued.*

Size (inches).	Sectional Area (square inches).	Weight (Iron).	Weight (Steel).
3¾ × ½	1.88	6.25	6.38
3¾ × ⅝	2.34	7.81	7.97
3¾ × ¾	2.81	9.38	9.56
3¾ × ⅞	3.28	10.9	11.16
3¾ × 1	3.75	12.5	12.75
4 × ¼	1.00	3.33	3.40
4 × ⅜	1.50	5.00	5.10
4 × ½	2.00	6.67	6.80
4 × ⅝	2.50	8.33	8.50
4 × ¾	3.00	10.0	10.20
4 × ⅞	3.50	11.7	11.90
4 × 1	4.00	13.3	13.60
4½ × ¼	1.13	3.75	3.83
4½ × ⅜	1.69	5.63	5.74
4½ × ½	2.25	7.50	7.65
4½ × ⅝	2.81	9.38	9.56
4½ × ¾	3.38	11.3	11.48
4½ × ⅞	3.94	13.1	13.39
4½ × 1	4.50	15.0	15.30
5 × ¼	1.25	4.17	4.25
5 × ⅜	1.88	6.25	6.38
5 × ½	2.50	8.33	8.50
5 × ⅝	3.13	10.4	10.63
5 × ¾	3.75	12.5	12.75
5 × ⅞	4.38	14.6	14.88
5 × 1	5.25	17.5	17.00
6 × ¼	1.50	5.00	5.10
6 × ⅜	2.25	7.50	7.65
6 × ½	3.00	10.0	10.20
6 × ⅝	3.75	12.5	12.75
6 × ¾	4.50	15.0	15.30
6 × ⅞	5.25	17.5	17.85
6 × 1	6.00	20.0	20.40
7 × ¼	1.75	5.83	5.95
7 × ⅜	2.63	8.75	8.93
7 × ½	3.50	11.7	11.90
7 × ⅝	4.38	14.6	14.88
7 × ¾	5.25	17.5	17.85
7 × ⅞	6.13	20.4	20.83
7 × 1	7.00	23.3	23.80
8 × ¼	2.00	6.67	6.80
8 × ⅜	3.00	10.0	10.20
8 × ½	4.00	13.3	13.60
8 × ⅝	5.00	16.7	17.00

TABLE XXII.—*Continued.*

Size (inches.)	Sectional Area (square inches).	Weight (Iron).	Weight (Steel).
8 × ¾	6.00	20.0	20.40
8 × ⅞	7.00	23.3	23.80
8 × 1	8.00	26.7	27.20
9 × ¼	2.25	7.50	7.65
9 × ⅜	3.38	11.3	11.48
9 × ½	4.50	15.0	15.30
9 × ⅝	5.63	18.8	19.13
9 × ¾	6.75	22.5	22.95
9 × ⅞	7.88	26.3	26.78
9 × 1	9.00	30.0	30.60
10 × ¼	2.50	8.33	8.50
10 × ⅜	3.75	12.5	12.75
10 × ½	5.00	16.7	17.00
10 × ⅝	6.25	20.8	21.25
10 × ¾	7.50	25.0	25.50
10 × ⅞	8.75	29.2	29.75
10 × 1	10.0	33.3	34.00
11 × ¼	2.75	9.17	9.35
11 × ⅜	4.13	13.8	14.03
11 × ½	5.50	18.3	18.70
11 × ⅝	6.88	22.9	23.38
11 × ¾	8.25	27.5	28.05
11 × ⅞	9.63	32.1	32.73
11 × 1	11.0	36.7	37.40
12 × ¼	3.00	10.0	10.20
12 × ⅜	4.50	15.0	15.30
12 × ½	6.00	20.0	20.40
12 × ⅝	7.50	25.0	25.50
12 × ¾	9.00	30.0	30.60
12 × ⅞	10.5	35.0	35.70
12 × 1	12.0	40.0	40.80

Table XXIII.

Weight of Round Bars of Iron and Steel in Lbs. per Lineal Foot.

Size of Bar, in inches.	Sectional Area (square inches).	Weight (Round Iron).	Weight (Round Steel).
$\frac{1}{4}$	.0491	.164	.167
$\frac{5}{16}$	.110	.368	.375
$\frac{3}{8}$	.196	.654	.667
$\frac{7}{16}$	.307	1.023	1.043
$\frac{9}{16}$	.442	1.473	1.502
$\frac{11}{16}$	.601	2.004	2.044
1	.785	2.618	2.670
$1\frac{1}{16}$	.994	3.313	3.380
$1\frac{1}{8}$	1.23	4.090	4.172
$1\frac{3}{16}$	1.48	4.949	5.049
$1\frac{1}{4}$	1.77	5.890	6.008
$1\frac{5}{16}$	2.07	6.912	7.051
$1\frac{3}{8}$	2.41	8.017	8.178
$1\frac{7}{16}$	2.76	9.203	9.388
2	3.14	10.471	10.681
$2\frac{1}{16}$	3.55	11.821	12.058
$2\frac{1}{8}$	3.98	13.252	13.519
$2\frac{3}{16}$	4.43	14.766	15.062
$2\frac{1}{4}$	4.91	16.361	16.690
$2\frac{5}{16}$	5.41	18.038	18.400
$2\frac{3}{8}$	5.94	19.797	20.195
$2\frac{7}{16}$	6.49	21.637	22.072
3	7.07	23.560	24.033
$3\frac{1}{4}$	8.30	27.650	28.206
$3\frac{1}{2}$	9.62	32.067	32.712
$3\frac{3}{4}$	11.0	36.812	37.552
4	12.6	41.884	42.726
$4\frac{1}{4}$	14.2	47.283	48.233
$4\frac{1}{2}$	15.9	53.009	54.075
$4\frac{3}{4}$	17.7	59.062	60.250
5	19.6	65.443	66.759
$5\frac{1}{4}$	21.7	72.151	73.602
$5\frac{1}{2}$	23.8	79.186	80.778
$5\frac{3}{4}$	26.0	86.549	88.288
6	28.3	94.238	96.133

TABLE XXIV.

WEIGHT OF SQUARE BARS OF IRON AND STEEL IN LBS. PER LINEAL FOOT.

Size of Bar, in inches.	Sectional Area (square inches).	Weight (Square Iron).	Weight (Square Steel).
$\frac{1}{4}$	.0625	.208	.213
$\frac{3}{8}$	.141	.469	.478
$\frac{1}{2}$	.25	.833	.850
$\frac{5}{8}$	.391	1.302	1.328
$\frac{3}{4}$	.563	1.875	1.913
$\frac{7}{8}$	.766	2.552	2.603
1	1.00	3.333	3.400
$1\frac{1}{8}$	1.27	4.219	4.303
$1\frac{1}{4}$	1.56	5.208	5.313
$1\frac{3}{8}$	1.89	6.302	6.428
$1\frac{1}{2}$	2.25	7.500	7.650
$1\frac{5}{8}$	2.64	8.802	8.978
$1\frac{3}{4}$	3.06	10.208	10.413
$1\frac{7}{8}$	3.52	11.719	11.953
2	4.00	13.333	13.600
$2\frac{1}{8}$	4.52	15.052	15.353
$2\frac{1}{4}$	5.06	16.875	17.213
$2\frac{3}{8}$	5.64	18.802	19.178
$2\frac{1}{2}$	6.25	20.833	21.250
$2\frac{5}{8}$	6.89	22.969	23.428
$2\frac{3}{4}$	7.56	25.208	25.713
$2\frac{7}{8}$	8.27	27.552	28.103
3	9.00	30.000	30.600
$3\frac{1}{4}$	10.6	35.208	35.913
$3\frac{1}{2}$	12.3	40.833	41.650
$3\frac{3}{4}$	14.1	46.875	47.813
4	16.0	53.333	54.400
$4\frac{1}{4}$	18.1	60.208	61.413
$4\frac{1}{2}$	20.3	67.500	68.850
$4\frac{3}{4}$	22.6	75.208	76.713
5	25.0	83.333	85.000
$5\frac{1}{4}$	27.6	91.875	93.713
$5\frac{1}{2}$	30.3	100.83	102.85
$5\frac{3}{4}$	33.1	110.21	112.41
6	36.0	120.00	122.40

TABLE XXV.

WEIGHT OF ANGLE AND TEE IRON IN LBS. PER LINEAL FOOT.

Sum of Width and Depth of Flanges, in inches.	MEAN THICKNESS OF WEBS IN PARTS OF AN INCH.											
	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{13}{16}$	$\frac{7}{8}$	$\frac{15}{16}$	1
$1\frac{1}{2}$	1.04	1.24	1.41	...	...	...	...	...	...	...	...	...	...
$1\frac{3}{4}$	1.25	1.50	1.72	...	...	...	...	...	...	...	...	...	...
2	1.46	1.76	2.03	2.28	...	...	...	...	...	...	...	...	...
$2\frac{1}{4}$	1.67	2.02	2.34	2.64	...	...	...	...	...	...	...	...	...
$2\frac{1}{2}$	1.88	2.28	2.66	3.01	3.33	...	...	...	...	...	..	...	...
$2\frac{3}{4}$	2.08	2.54	2.97	3.37	3.75	...	...	...	...	...	...	...	...
3	2.29	2.80	3.28	3.74	4.17	4.57	...	...	...	...	...	...	...
$3\frac{1}{4}$	2.50	3.06	3.59	4.10	4.58	5.03	...	...	...	...	...	...	...
$3\frac{1}{2}$	2.71	3.32	3.91	4.47	5.00	5.51	5.99	...	...	...	...	...	...
$3\frac{3}{4}$	2.92	3.58	4.22	4.83	5.42	5.98	6.51	...	...	...	...	...	...
4	3.13	3.84	4.53	5.20	5.83	6.45	7.03	7.59	...	...	...	...	...
$4\frac{1}{4}$	3.33	4.10	4.84	5.56	6.25	6.91	7.55	8.16	...	...	...	...	...
$4\frac{1}{2}$	3.54	4.36	5.16	5.92	6.67	7.38	8.07	8.74	9.38	...	...	...	...
$4\frac{3}{4}$	3.75	4.62	5.47	6.29	7.08	7.85	8.59	9.31	10.00	...	...	...	...
5	3.96	4.88	5.78	6.65	7.50	8.32	9.11	9.88	10.63	11.34	...	...	...
$5\frac{1}{4}$	4.17	5.14	6.09	7.02	7.92	8.79	9.64	10.46	11.25	12.02	...	...	...
$5\frac{1}{2}$	4.38	5.40	6.41	7.38	8.33	9.26	10.16	11.03	11.88	12.69	13.49	...	...
$5\frac{3}{4}$	4.58	5.66	6.72	7.75	8.75	9.73	10.68	11.60	12.50	13.37	14.22	...	...
6	4.79	5.92	7.03	8.11	9.17	10.20	11.20	12.17	13.13	14.05	14.95	15.82	...
$6\frac{1}{4}$	5.00	6.18	7.34	8.48	9.58	10.66	11.72	12.75	13.75	14.72	15.68	...	...
$6\frac{1}{2}$	5.21	6.45	7.66	8.84	10.00	11.13	12.24	13.32	14.38	15.40	16.41	...	...
$6\frac{3}{4}$	5.42	6.71	7.97	9.21	10.42	11.60	12.76	13.89	15.00	16.08	17.14	...	...
7	5.63	6.97	8.28	9.57	10.83	12.07	13.28	14.46	15.63	16.76	17.86	18.95	20.00

TABLE XXV.—*Continued.*

Sum of Width and Depth of Flanges, in inches.	Mean Thickness of Web in Parts of an Inch.												
	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{13}{16}$	$\frac{7}{8}$	$\frac{15}{16}$	1
$7\frac{1}{4}$	5.83	7.23	8.59	9.93	11.25	12.54	13.80	15.04	16.25	17.43	18.59	19.73	20.83
$7\frac{1}{2}$	6.04	7.49	8.91	10.30	11.67	13.01	14.32	15.61	16.88	18.11	19.32	20.51	21.67
$7\frac{3}{4}$	6.25	7.75	9.22	10.66	12.08	13.48	14.84	16.18	17.50	18.79	20.05	21.29	22.50
8	6.46	8.01	9.53	11.03	12.50	13.95	15.36	16.76	18.13	19.47	20.78	22.07	23.33
$8\frac{1}{4}$	6.67	8.27	9.84	11.39	12.92	14.44	15.89	17.33	18.75	20.14	21.51	22.85	24.17
$8\frac{1}{2}$	6.88	8.53	10.16	11.76	13.33	14.88	16.41	17.90	19.38	20.82	22.24	23.63	25.00
$8\frac{3}{4}$	7.08	8.79	10.47	12.12	13.75	15.35	16.93	18.48	20.00	21.50	22.97	24.41	25.83
9	7.29	9.05	10.78	12.49	14.17	15.82	17.45	19.05	20.63	22.17	23.70	25.20	26.67
$9\frac{1}{4}$	7.50	9.31	11.09	12.85	14.58	16.29	17.97	19.62	21.25	22.85	24.43	25.98	27.50
$9\frac{1}{2}$	7.71	9.57	11.41	13.22	15.00	16.76	18.49	20.20	21.88	23.53	25.16	26.76	28.33
$9\frac{3}{4}$	7.92	9.83	11.72	13.58	15.42	17.23	19.01	20.77	22.50	24.21	25.89	27.54	29.17
10	8.13	10.09	12.03	13.95	15.83	17.70	19.53	21.34	23.13	24.88	26.61	28.32	30.00
$10\frac{1}{4}$	8.33	10.35	12.34	14.31	16.25	18.16	20.05	21.91	23.75	25.56	27.34	29.10	30.83
$10\frac{1}{2}$	8.54	10.61	12.66	14.67	16.67	18.63	20.57	22.49	24.38	26.24	28.07	29.88	31.67
$10\frac{3}{4}$	8.75	10.87	12.97	15.04	17.08	19.10	21.09	23.06	25.00	26.91	28.80	30.66	32.50
11	8.96	11.13	13.28	15.40	17.50	19.51	21.61	23.63	25.63	27.59	29.53	31.45	33.33
$11\frac{1}{4}$	9.17	11.39	13.59	15.77	17.92	20.04	22.14	24.21	26.25	28.27	30.26	32.23	34.17
$11\frac{1}{2}$	...	...	13.91	16.13	18.33	20.51	22.66	24.78	26.88	29.85	30.99	33.01	35.00
$11\frac{3}{4}$	...	...	14.22	16.50	18.75	20.98	23.18	25.55	27.50	29.62	31.72	33.79	35.83
12	...	...	14.53	16.86	19.17	21.45	23.70	25.92	28.13	30.30	32.45	34.57	36.67
$12\frac{1}{4}$	...	...	14.84	17.23	19.58	21.91	24.22	26.50	28.75	30.98	33.18	35.35	37.50
$12\frac{1}{2}$	...	...	15.16	17.59	20.00	22.38	24.74	27.07	29.38	31.65	33.91	36.13	38.33
$12\frac{3}{4}$	...	...	15.47	17.96	20.42	22.85	25.26	27.64	30.00	32.33	34.64	36.91	39.17
13	...	...	15.78	18.32	20.83	23.32	25.78	28.22	30.63	33.01	35.36	37.70	40.00

TABLE XXV.—*Continued.*

Sum of Width and Depth of Flanges, in inches.	MEAN THICKNESS OF WEB IN PARTS OF AN INCH.												
	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1
13 1/4	...	...	16.09	18.68	21.25	23.79	26.30	28.79	31.25	33.68	36.09	38.48	40.83
13 1/2	...	...	16.41	19.05	21.67	24.26	26.82	29.36	31.88	34.36	36.82	39.26	41.67
13 3/4	...	...	16.72	19.41	22.08	24.73	27.34	29.93	32.50	35.04	37.55	40.04	42.50
14	...	...	17.03	19.78	22.50	25.20	27.86	30.51	33.13	35.72	38.28	40.82	43.33
14 1/4	...	...	17.34	20.14	22.92	25.66	28.39	31.08	33.75	36.39	39.01	41.60	44.17
14 1/2	...	...	17.66	20.51	23.33	26.13	28.91	31.65	34.38	37.07	39.74	42.38	45.00
14 3/4	...	...	17.97	20.87	23.75	26.60	29.43	32.23	35.00	37.75	40.47	43.16	45.83
15	...	...	18.28	21.24	24.17	27.07	29.95	32.80	35.63	38.43	41.20	43.95	46.67

TABLE XXVI.

WEIGHT OF ANGLE AND TEE STEEL IN LBS. PER LINEAL FOOT.

Sum of Width and Depth of Flanges, in inches.	MEAN THICKNESS OF WEB IN PARTS OF AN INCH.												
	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1
1 1/2	1.06	1.26	...	...	...	...	...	...	...	...	...	...	...
1 3/4	1.27	1.53	...	...	...	...	...	...	...	...	...	...	...
2	1.48	1.79	2.07	...	...	...	...	...	...	...	...	...	...
2 1/4	1.70	2.06	2.39	...	...	...	...	...	...	...	...	...	...
2 1/2	1.91	2.32	2.71	3.07	...	...	...	...	...	...	...	...	...
2 3/4	2.12	2.59	3.03	3.44	...	...	...	...	...	...	...	...	...
3	2.33	2.86	3.35	3.81	4.25	...	...	...	...	...	...	...	...

TABLE XXVI.—*Continued.*

Sum of Width and Depth of Flanges, in inches.	MEAN THICKNESS OF WEB IN PARTS OF AN INCH.												
	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{13}{16}$	$\frac{7}{8}$	$\frac{15}{16}$	1
$3\frac{1}{4}$	2.55	3.12	3.67	4.18	4.68	...	...	...	...	...	...	...	...
$3\frac{1}{2}$	2.76	3.39	3.98	4.56	5.10	5.62	...	...	...	...	...	...	...
$3\frac{3}{4}$	2.97	3.65	4.30	4.93	5.53	6.10	...	...	...	...	...	...	...
4	3.18	3.92	4.62	5.30	5.95	6.57	7.17	...	...	...	...	...	...
$4\frac{1}{4}$	3.40	4.18	4.94	5.67	6.38	7.05	7.70	...	...	...	...	...	...
$4\frac{1}{2}$	3.61	4.45	5.26	6.04	6.80	7.53	8.23	8.91	...	...	...	...	...
$4\frac{3}{4}$	3.82	4.71	5.58	6.41	7.23	8.01	8.77	9.50	...	...	...	...	...
5	4.03	4.98	5.90	6.79	7.65	8.49	9.30	10.08	10.84	...	...	...	...
$5\frac{1}{4}$	4.25	5.25	6.22	7.16	8.08	8.96	9.83	10.66	11.48	12.26	...	...	...
$5\frac{1}{2}$	4.46	5.51	6.53	7.53	8.50	9.44	10.36	11.25	12.11	12.95	13.76	...	...
$5\frac{3}{4}$	4.67	5.78	6.85	7.90	8.93	9.92	10.89	11.83	12.75	13.64	14.50	...	...
6	4.89	6.04	7.17	8.27	9.35	10.40	11.42	12.42	13.39	14.33	15.25	...	...
$6\frac{1}{4}$	5.10	6.31	7.49	8.65	9.78	10.88	11.95	13.00	14.03	15.02	15.99	...	...
$6\frac{1}{2}$	5.31	6.57	7.81	9.02	10.20	11.36	12.48	13.59	14.66	15.71	16.73	...	...
$6\frac{3}{4}$	5.53	6.84	8.13	9.39	10.63	11.83	13.02	14.17	15.30	16.40	17.48	...	...
7	5.74	7.11	8.45	9.76	11.05	12.31	13.55	14.76	15.94	17.09	18.22	19.32	...
$7\frac{1}{4}$	5.95	7.37	8.77	10.13	11.48	12.79	14.08	15.34	16.58	17.78	18.97	20.12	...
$7\frac{1}{2}$	6.16	7.64	9.08	10.51	11.90	13.27	14.61	15.92	17.21	18.47	19.71	20.92	22.10
$7\frac{3}{4}$	6.38	7.90	9.40	10.88	12.33	13.75	15.14	16.51	17.85	19.16	20.45	21.71	22.95
8	6.59	8.17	9.72	11.25	12.75	14.22	15.67	17.09	18.49	19.85	21.20	22.51	23.80
$8\frac{1}{4}$	6.80	8.43	10.04	11.62	13.18	14.70	16.20	17.68	19.13	20.55	21.94	23.31	24.65
$8\frac{1}{2}$	7.01	8.70	10.36	11.99	13.60	15.18	16.73	18.26	19.76	21.24	22.68	24.11	25.50
$8\frac{3}{4}$	7.23	8.96	10.68	12.36	14.03	15.66	17.27	18.85	20.40	21.93	23.43	24.90	26.35
9	7.44	9 23	11.00	12.74	14.45	16.14	17.80	19.43	21.04	22.62	24.17	25.70	27.20

TABLE XXVI.—*Continued.*

Sum of Width and Depth of Flanges, in inches.	Mean Thickness of Web in Parts of an Inch.												
	¼	5/16	⅜	7/16	½	9/16	⅝	11/16	¾	13/16	⅞	15/16	1
9¼	7.65	9.50	11.32	13.11	14.88	16.61	18.33	20.01	21.68	23.31	24.92	26.50	28.05
9½	7.86	9.76	11.63	13.48	15.30	17.09	18.86	20.60	22.31	24.00	25.66	27.29	28.90
9¾	8.08	10.03	11.95	13.85	15.73	17.57	19.39	21.18	22.95	24.69	26.40	28.09	29.75
10	8.29	10.29	12.27	14.22	16.15	18.05	19.92	21.77	23.59	25.38	27.15	28.89	30.60
10¼	8.50	10.56	12.59	14.60	16.58	18.53	20.45	22.35	24.23	26.07	27.89	29.68	31.45
10½	8.71	10.82	12.91	14.97	17.00	19.01	20.98	22.94	24.86	26.76	28.63	30.48	32.30
10¾	8.93	11.09	13.23	15.34	17.43	19.48	21.52	23.52	25.50	27.45	29.38	31.28	33.15
11	9.14	11.36	13.55	15.71	17.85	19.96	22.05	24.11	26.14	28.14	30.12	32.07	34.00
11¼	9.35	11.62	13.87	16.08	18.28	20.44	22.58	24.69	26.78	28.83	30.87	32.87	34.85
11½	9.56	11.89	14.18	16.46	18.70	20.92	23.11	25.27	27.41	29.52	31.61	33.67	35.70
11¾	9.78	12.15	14.50	16.83	19.13	21.40	23.64	25.86	28.06	30.21	32.35	34.46	36.55
12	9.99	12.42	14.82	17.20	19.55	21.87	24.17	26.44	28.69	30.91	33.10	35.26	37.40
12¼	10.20	12.68	15.14	17.57	19.98	22.35	24.70	27.03	29.33	31.60	33.84	36.06	38.25
12½	10.41	12.95	15.46	17.94	20.40	22.83	25.23	27.61	29.96	32.29	34.58	36.86	39.10
12¾	10.63	13.21	15.78	18.31	20.83	23.31	25.77	28.20	30.60	32.98	35.33	37.65	39.95
13	10.84	13.48	16.10	18.69	21.25	23.79	26.30	28.78	31.24	33.67	36.07	38.45	40.80
13¼	11.05	13.75	16.42	19.06	21.68	24.26	26.83	29.36	31.88	34.36	36.82	39.25	41.65
13½	11.26	14.01	16.73	19.43	22.10	24.74	27.36	29.95	32.51	35.05	37.56	40.04	42.50
13¾	11.48	14.28	17.05	19.80	22.53	25.22	27.89	30.53	33.15	35.74	38.30	40.84	43.35
14	...	14.54	17.37	20.17	22.95	25.70	28.42	31.12	33.79	36.43	39.05	41.64	44.20
14¼	...	14.81	17.69	20.55	23.38	26.18	28.95	31.70	34.43	37.12	39.70	42.43	45.05
14½	...	15.07	18.01	20.92	23.80	26.66	29.48	32.29	35.06	37.81	40.53	43.23	45.90
14¾	...	15.34	18.33	21.29	24.23	27.13	30.02	32.87	35.70	38.50	41.28	44.03	46.75
15	...	15.61	18.65	21.66	24.65	27.61	30.55	33.46	36.34	39.19	42.02	44.82	47.60

TABLE XXVII.

TABLE TO FACILITATE THE CALCULATION OF A NUMBER OF RIVETS OF A GIVEN PITCH IN A GIVEN LENGTH.

No. of Rivets.	PITCH.													
1	Ft. Ins. 2	Ft. Ins. $2\frac{1}{4}$	Ft. Ins. $2\frac{1}{2}$	Ft. Ins. $2\frac{3}{4}$	Ft. Ins. 3	Ft. Ins. $3\frac{1}{4}$	Ft. Ins. $3\frac{1}{2}$	Ft. Ins. $3\frac{3}{4}$						
	LENGTHS.													
2	4	$4\frac{1}{2}$	5	$5\frac{1}{2}$	6	$6\frac{1}{2}$	7	$7\frac{1}{2}$						
3	6	$6\frac{3}{4}$	$7\frac{1}{2}$	$8\frac{1}{4}$	9	$9\frac{3}{4}$	$10\frac{1}{2}$	$11\frac{1}{4}$						
4	8	9	10	11	1 0	1 1	1 2	1 3						
5	10	$11\frac{1}{4}$	1 $0\frac{1}{2}$	1 $1\frac{3}{4}$	1 3	1 $4\frac{1}{4}$	1 $5\frac{1}{2}$	1 $6\frac{3}{4}$						
6	1 0	1 $1\frac{1}{2}$	1 3	1 $4\frac{1}{2}$	1 6	1 $7\frac{1}{2}$	1 9	1 $10\frac{1}{2}$						
7	1 2	1 $3\frac{3}{4}$	1 $5\frac{1}{2}$	1 $7\frac{1}{4}$	1 9	1 $10\frac{3}{4}$	2 $0\frac{1}{2}$	2 $2\frac{1}{4}$						
8	1 4	1 6	1 8	1 10	2 0	2 2	2 4	2 6						
9	1 6	1 $8\frac{1}{4}$	1 $10\frac{1}{2}$	2 $0\frac{3}{4}$	2 3	2 $5\frac{1}{4}$	2 $7\frac{1}{2}$	2 $9\frac{3}{4}$						
10	1 8	1 11	2 1	2 $3\frac{1}{2}$	2 6	2 $8\frac{1}{2}$	2 11	3 $1\frac{1}{2}$						
No. of Rivets in a length of 10 ft.	60	53	48	43	40	36	34	32						

TABLE XXVIII.

FRACTIONAL PARTS OF A POUND AVOIRDUPOIS AND THEIR DECIMAL EQUIVALENTS.

Ounces.	Lbs.	Ounces.	Lbs.
$\frac{1}{4}$	.015625	$8\frac{1}{2}$	.53125
$\frac{1}{2}$	.03125	9	.5625
1	.0625	$9\frac{1}{2}$	.59375
$1\frac{1}{2}$	.09375	10	.625
2	.125	$10\frac{1}{2}$	.65625
$2\frac{1}{2}$	.15625	11	.6875
3	.1875	$11\frac{1}{2}$	.71875
$3\frac{1}{2}$	.21875	12	.75
4	.25	$12\frac{1}{2}$	.78125
$4\frac{1}{2}$	.28125	13	.8125
5	.3125	$13\frac{1}{2}$	.84375
$5\frac{1}{2}$	.34375	14	.875
6	.375	$14\frac{1}{2}$	.90625
$6\frac{1}{2}$	.40625	15	.9375
7	.4375	$15\frac{1}{2}$	.96875
$7\frac{1}{2}$	.46875	16	1.000
8	.5	...	...

Table XXIX.

Fractional Parts of an Inch and their Decimal Equivalents.

$\frac{1}{32}$	=	.03125	$\frac{17}{32}$	=	.53125
$\frac{1}{16}$	=	.0625	$\frac{9}{16}$	=	.5625
$\frac{3}{32}$	=	.09375	$\frac{19}{32}$	=	.59375
$\frac{1}{8}$	=	.125	$\frac{5}{8}$	=	.625
$\frac{5}{32}$	=	.15625	$\frac{21}{32}$	=	.65625
$\frac{3}{16}$	=	.1875	$\frac{11}{16}$	=	.6875
$\frac{7}{32}$	=	.21875	$\frac{23}{32}$	=	.71875
$\frac{1}{4}$	=	.25	$\frac{3}{4}$	=	.75
$\frac{9}{32}$	=	.28125	$\frac{25}{32}$	=	.78125
$\frac{5}{16}$	=	.3125	$\frac{13}{16}$	=	.8125
$\frac{11}{32}$	=	.34375	$\frac{27}{32}$	=	.84375
$\frac{3}{8}$	=	.375	$\frac{7}{8}$	=	.875
$\frac{13}{32}$	=	.40625	$\frac{29}{32}$	=	.90625
$\frac{7}{16}$	=	.4375	$\frac{15}{16}$	=	.9375
$\frac{15}{32}$	=	.46875	$\frac{31}{32}$	=	.96875
$\frac{1}{2}$	=	.5	1	=	1.0

TABLE XXX.

INCHES AND PARTS AND THEIR EQUIVALENT DECIMALS OF A FOOT.

Inches.	Equivalents.	Inches.	Equivalents.	Inches.	Equivalents.
1/16	.0052083	2 1/2	.2083	5 7/8	.489583
1/12	.010416	2 5/8	.21875	6	.5
3/16	.015625	2 3/4	.22916	6 1/4	.52083
1/4	.02083	2 7/8	.239583	6 1/2	.5416
5/16	.0260416	3	.25	6 3/4	.5625
3/8	.03125	3 1/8	.260416	7	.583
7/16	.0364583	3 1/4	.27083	7 1/4	.60416
1/2	.0416	3 3/8	.28125	7 1/2	.625
9/16	.046875	3 1/2	.2916	7 3/4	.64583
5/8	.052083	3 5/8	.302083	8	.6666
11/16	.0572916	3 3/4	.3125	8 1/4	.6875
3/4	.0625	3 7/8	.322916	8 1/2	.7083
13/16	.0677083	4	.3333	8 3/4	.72916
7/8	.072916	4 1/8	.34375	9	.75
15/16	.078125	4 1/4	.35416	9 1/4	.77083
1	.083	4 3/8	.364583	9 1/2	.7916
1 1/8	.09375	4 1/2	.375	9 3/4	.8125
1 1/4	.10416	4 5/8	.385416	10	.8333
1 3/8	.114583	4 3/4	.39583	10 1/4	.85416
1 1/2	.125	4 7/8	.40625	10 1/2	.875
1 5/8	.135416	5	.416	10 3/4	.89583
1 3/4	.14583	5 1/8	.427083	11	.916
1 7/8	.15625	5 1/4	.4375	11 1/4	.9375
2	.16	5 3/8	.447916	11 1/2	.9583
2 1/8	.177083	5 1/2	.4583	11 3/4	.97916
2 1/4	.1875	5 5/8	.46875	12	1.00
2 3/8	.197916	5 3/4	.47916	...	...

TABLE XXXI.

COMPARATIVE WEIGHTS OF DIFFERENT BODIES.

Cast Iron = 1.	Bar Iron = 1.	Steel = 1.	Brass = 1.
Bar Iron = 1.048	Cast Iron = .953	Cast Iron = .925	Cast Iron = .867
Steel = 1.076	Steel = 1.026	Bar Iron = .973	Bar Iron = .909
Brass = 1.153	Brass = 1.1	Brass = 1.07	Steel = .933
Copper = 1.213	Copper = 1.151	Copper = 1.123	Copper = 1.05
Gun Metal = 1.208	Gun Metal = 1.150	Gun Metal = 1.121	Gun Metal = 1.046
Lead = 1.564	Lead = 1.5	Lead = 1.453	Lead = 1.357

Copper = 1.	Gun Metal = 1.	Lead = 1.	Yellow Pine = 1.
Cast Iron = .83	Cast Iron = .8288	Cast Iron = .64	Cast Iron = 16.0
Bar Iron = .866	Bar Iron = .8687	Bar Iron = .67	Steel = 17.0
Steel = .89	Steel = .8917	Steel = .688	Brass = 18.8
Brass = .95	Brass = .9558	Brass = .737	Gun Metal = 19.0
Gun Metal = .99	Copper = 1.0004	Copper = .774	Copper = 19.3
Lead = 1.29	Lead = 1.292	Gun Metal = .773	Lead = 24.0

INDEX.

ACCUMULATOR, 225, 230
Adamson's seams, 199
Angle-iron frames, 167-175
— joints, 241
— rings, bending of, 127-132
— rings, lengths for, 259-262
— smiths, 2
Angle irons and steels, 64-66
— irons, bolt centres in, 335
— irons, machine for bending, 146, 319
Angles and tees, weight of, 358-362
— &c., bending of, 115-151
— blocks for bending, 119, 120
— cutting block for, 75-77
— furnace for heating, 151
— machine for bending, 319
— machine for bevelling, 320
— sawing of, 75
Angular forms, bending of, 135-140
Annular vessels, 292
Anvil for welding, 181, 182
Appendix, 331-366
Area, contraction of, 42
Areas, &c., table of, 336-339
Averaging areas, 292-294

BAR iron and steel, weight of, 352-357
Bars, punching of, 207
Beam compasses, 19
Bending angle irons, machine for, 146, 310
— angles, &c., 115-151
— angles and tees, machine for, 319
— blocks, 111, 114, 119, 120
— conical forms, 108, 109
— envelopes of spheres, 110, 111
— of angular forms, 135-140
— of channels, 141
— of foundation ring, 141-144
— of H-sections, 141
— of manhole ring, 144, 145
— of plates, 92-114
— of plates to regular curves, 102, 103
— of rails, 140, 141
— of rings, 107, 108
— of tees, 138, 140
— rolls, 98-108, 298-301
— rolls, action of, 101, 102
— rolls, elasticity of, 104
— rolls, gearing of, 104, 106
— rolls, imperfections of, 103, 104
— rolls, method of action of, 101, 102
— sections of plates, 109, 110
— the edges of plates, 103, 104
— thick plates, 103
— to curves, 121-141
Bessemer process, 31
Bevelled iron, 65, 67
Blisters, 32, 33

Block for bevelling and bending, 117, 118
Blocks for bending iron rings, 128
— stand for, 118
Boiler flue drilling machines, 310, 312
— shell drilling machines, 309, 310
Bolsters, 208-211
Brackets in girder work, 250, 251
Brands for steel, 54
Breaking strength, 41
Bricked-up fire, 153, 154, 168
Built-up girders, 245-250
Burrs, 172, 179
Butt joints, 240, 241

CALIPERS, 22
Caulking, 215-217
— of tanks, 217
— pneumatic, 327
— tools, 16, 216, 327
Centre popping, 204
— punch, 18
Centring tool, 18, 19
Channels, 65. 66
— bending of, 141
Chisels, 6-8
Circles, 289, 290
— table of proportions, 336-349
Circular rings, 290
— rings, lengths for, 259
Circumferences, &c., tables of, 336-349
Clamps, 22
Combined punching machines, 307
Comparative weights, 366
Compasses, 19
Compound girders, 244, 245
Cones, 292
Conical plates, bending of, 108, 109
— stand or mandrel, 121, 122
— water tube, 280-282
Conic frustum, envelope of, 272, 273
Contraction of area, 42
Convex irons, 65, 67
Copper, 37-39
— experiments on, 39
— how worked, 38
— impurities in ore, 37
— its employment by boiler-makers, 38
— strength of, as affected by temperature, 37-39
Cost of work, 283
Countersinking, 311
Countersunk rivets, 217
Covering strips, 240, 241
Cracks in welds, 179
Crane, 228, 233
Crinkling or puckering, 127, 135
Cubes, &c., tables of, 336-349
Curved edges, cutting of, 77-80
Curves of large radii, 269-272
Cutting blocks, 75-77
— curved edges, 77-80
— out rivets, 217
— plates, 70-80
— section irons, 70-76
Cylinders, 292
Cylindrical parts, fitting of, 273-276

DECIMAL equivalents of a foot, 365
— equivalents of an inch, 364
— equivalents of a pound, 363
Decimals, the use of, 288
Development of conical water tubes, 280-282
— of envelope of conic frustum, 272, 273
— of envelopes of spheres, 276-281
— of surfaces, 267-282
Diameters, circumferences, &c., table of, 336-349
Dies for punching, 208-211
Dividing wheel, 20

Division of girders, 250, 251
Dollys, 22
Domes and pipes, 274, 275
Double girders, 247, 248
Drifts, 17
Drilling machines, 308-313
— machines for flues, 310, 311
— machines for shells, 309-310
Drills, 23
Ductility and strength in iron and steel, 36, 37
— of iron and steel, 34, 35
— of materials, 42

EDGES, planing of, 76, 77
Elastic limit, 42, 43, 44
Electric riveting, 326
Ellipse, 282
Elliptical rings, length for, 262
Elongation before fracture, 41
Envelopes of conic frustum, 272, 273
— of spheres, 276-281
— of spheres, bending of, 110, 111
Enveloping surfaces, 291
Estimates for cost of work, 283
Estimation of lengths of material, 258-264
— of temperatures, 157
— of weights, 283-294
Extras, 68

FACTOR of safety, 42
Fibre, nicking test for, 49
— or grain in iron and steel, 35, 36
Fire-box shell, setting out of, 198, 199
— for welding, 153-155, 168
— hole ring, 158, 159
Fixed riveters, 220, 221, 225, 227, 232, 233-236
Flange, checking of, 191, 192
Flanged joints, 242
Flanging, 184-202
— circular plates, 189-194
— flat rectangular plates, 187-189
— flues, machines for, 200, 320
— machines, 199-202, 313-320
— tubes, 194-198
Flats, 64, 65
Flattening machine, 85, 86
— rolls, 302
Flatters, 9, 10
Forge, 115-118
— tests for iron and steel rivets, 55, 56
— tests for steel bars, 56, 57
— tests for steel plates, 54, 55
— tests for iron angles, 50
— tests for iron bars, 49, 50
— tests for iron plates, 48
Foundation ring, bending of, 141 144
— ring, welding of, 159-164
Fullers, 10, 11
Furnace for heating angles, 151
— for rivets, 224, 327
— portable, for welding, 180, 181
— tubes, 243

GAP gauge, 22, 23
Girders, built-up, 245-247
— compound, 244, 245
— division of, 250, 251
— double, 247, 248
— joint in, 247, 248
— single, 245-247
Girder work, 243-250
Glut joints, 172, 173
— strips, 176, 177, 182
— welds, 176, 177
Gluts, 159, 164
Grain or fibre in iron and steel, 35, 36

HAMMER, holding - up, 214, 215
— scaling, 1
— set, 10
— sledge, 15
— welding, 317
Hammers, 13-15
Hand riveting, 218
Heaters, 250
Heat for welding, 156, 157
Hexagon irons, 65, 67
H-irons, 65, 66
Holding-up hammer, 214, 215
Holes, punched, 203-211
Hollow fire, 153, 154
Horizontal punching machine, 306-307
H-sections, bending of, 141
Hydraulic machines for flanging, 200-202, 313-319
— riveting, 219-223, 224-236, 321-325

INCHES, united, 69
Independent machines, 100
Ingot iron, 32
Ingots, 31
Iron and steel, comparison between, 31, 32
— and steel, relation of strength to ductility, 36, 37
— bar, weight of, 352-357
— direction of grain, 35, 36
— ductility of, 34, 35
— for welding, 177
— limiting sizes, 36
— plates, maximum dimensions of, 60-63
— plates, various qualities of, 45-48
— rivets, 217
— rivets, forge tests for, 55, 56
— saws, 73, 74
— sheet, table of weights, 350-351
Iron tests for, 33, 34
Irons, section, 49

JOINTS, butt, 240, 241
— flanged, 242
— in girders, 247, 248, 251, 255
— lap, 237, 238
— made with angle irons, 241
— riveted, 237-257
Joists, 65, 66

LAMINATION, 32, 33
Lap joints, 237, 238
— welds, 164, 175, 176
Lengths of material, to estimate, 258-264
Levelling blocks, 80, 81, 117, 118
Limiting dimensions and weights of materials, 60
— sizes in iron and steel, 36

MACHINE for bending angle irons, 146, 319
— for flanging, 199-202, 313-320
— riveting, 218, 322-326
Machines, 295-328
— for bending angles and tees, 319
— for bevelling angles, 319
— capacity and weight of, 295
— combined, 70, 307
— drilling, 308, 312
— flattening, 85, 86, 89-91, 302
— for flanging, 313, 320
— for flanging flues, 200, 320
— for punching, 70-72, 205, 303-307
— increase in capacity and weight, 295
— independent, 100
— shearing, 70-73
— straightening, 85, 86, 89-91, 302

Mandrel, conical, for rings, 121, 122
Mandrels for welding, 176, 179-183
Mangle, 85, 86
Manhole ring, bending of, 144, 145
— ring, welding of, 158
Mallet, 16, 196
Marking out of work, 265-282
Materials, 24-39
— diversity in quality, 24
— limiting dimensions and weights of, 60
— testing of, 40-57
Maximum dimensions of plates, 60-63
Mensuration, 287-294
Mild steels, 29-37
— steels, method of production, 30, 31
— steel, various qualities of, 50, 51
Multiple punching machine, 307
Multipliers, some useful, 285, 286
— the use of, 284, 286

NICKING test for fibre, 49
Non-homogeneity of iron, 29
Notching for bending, 135-137

OCTAGON irons, 65, 67
Octagons, 293
Open-hearth methods, 30
Ordering plates, 74, 75
Oval irons, 65, 67

PARALLELOGRAMS, 287, 288, 292
Piling of wrought iron, 27, 28
Planed edges, 76, 77
Planing, 77, 78
— machine, 77, 78, 296, 297
Plate bending rolls, 99-108, 298-301
— edge planing machine, 77, 78, 296, 297
— furnace, 92-99
Platers, 2
Plates, bending of, 92-114
— circular flanging, 189, 194
— cutting and straightening of, 70-86
— ordering of, 74, 75
— punching of, 206
— rectangular, flanging of, 187-189
— riveting of, 212
— sketch, 75
— steel and iron, maximum dimensions of, 60-63
— straightening of, with the hammer, 81, 84
— straightening of, in the rolls, 84-86
— weight of, 351
Plating, isolation of the trade, 3
— its literature, 5
— its recent development, 4
— learning the trade, 3
— and boiler-making, subdivision of the work, 1
— the trade, 1-5
— wages, 3
— square, 258
— telescopic, 259
Pneumatic riveting, 223, 324-326
Podger, 18
Polygons, 289, 290
Popping, 204
Portable anvil for welding, 181, 182
— furnace for welding, 180, 181
— riveters, 221-223, 226-233, 321-326
Porter bar, 171, 173
Prices of work, 263, 264
Proportion of rivets, 218
Puckering or crinkling, 127, 135
Puddling of wrought iron, 26-29
Pumps, 224, 227
Punches, 208-211
— taper of, 210

Punching, 203-211
— and shearing machines, 303-307
— machine, 205, 206
— machines, 70-72
— machines, combined, 307
— machines, horizontal, 306, 307
— machines, multiple, 307
— of bars, 207
— plates, 206
— supporting work during, 206, 208
Punch, rivet, 17
Pyramids, 292

QUADRILATERALS, 289

RAILS, bending of, 140, 141
Reamering punched holes, 213
Rectangular bodies, 291, 292
Reverberatory furnace, 92-99
Rig-up for flanging plates, 187-194
— for welding, 169-183
— for welding tubes, 182, 183
Rings, angle iron, lengths for, 259-269
— bending of, 107, 108
— circular, lengths for, 259
— elliptical, lengths for, 262
— of angle iron, bending of, 127-132
— stand or mandrel for, 121, 122
— tee iron, lengths for, 262
Riveted joints, proportions of, 331-335
— joints, types of, 237-257
Riveters, 2
— fixed, 220, 221, 225, 227, 232, 233-236
— portable, 221, 223, 226, 230-233, 321-326
— sets of, 214
Rivet furnace, 224, 327
— joints, mode of failure of, 237, 238
— loss of strength due to, 238, 239
— punch, 17
— set, 17
— snap, 21
Riveting, 218-236, 322-326
— electric, 326
— dollys, 22
— hydraulic, 219-223, 224-236, 321-325
— machine and hand, compared, 218
— pneumatic, 223, 324-326
Rivets, countersunk, 217
— cutting out of, 217
— iron and steel, forge tests for, 55, 56
— proportion of, 218
— table to facilitate calculations for, 363
Rolled sections, 64-69
Rolls, 99-108
— bending, 298-301
— flattening, 85, 86, 302
Rounds, 64, 65, 68
Rule measurement, 267

SAWING angles, 75
Saws, 73, 74
— for cold iron, 328
Scaling hammer, 15
Scrape, 21
Scribers, 19, 20
Seams, Adamson's, 119
Section irons, 49, 64-69
— irons, bending to curves, 121-141
Sectors, 290, 293
Segments, 290
Set hammer, 10
Sets of riveters, 214
Sett, rivet, 17

Setting down angles and tees, 185-187
Setts, 6-8
Shearing machines, 70-73
Sheet iron gauge, table of weights, 350, 351
Siemens' steel, 30
Single girders, 245-247
Sketch plates. 75
Sledge hammers, 15
Smiths, angle iron, 2
Snap, 21
Spanner and podger, 18
Sphere, zone of, 291
Spheres, 291, 292
— envelopes of, 276-281
Square plating, 258
Squares, 64, 65, 68
— &c., table of, 336-349
Squeezers, 89-91
Squeezing, 89-91
Stand for blocks, 118
Steel and iron, comparison between, 31, 32
— and iron, relation of strength to ductility, 36, 37
— bar, weight of, 342-347
— bars, forge test for, 56, 57
— brands for, 54
— direction of grain, 35, 36
— ductility of, 34, 35
— ingots, 31
— limiting sizes, 36
— mild, various qualities of, 50, 51
— plates, maximum dimensions of, 60, 63
— plate, forge test for, 54, 55
— rivets, 217
— rivets, forge tests for, 55, 56
— temper test for, 51
— tensile tests of, 51
— tests for, 33, 34, 51
— the use of, 4
Straightening block, 86-88
Straightening machines, 85, 86, 89-91, 302
— plates, 80, 86
— in the rolls, 84-86
— plates with the hammer, 81-84
— section iron, 89-91
Strength and ductility in iron and steel, 36, 37
— breaking, 41
— maximum and minimum, 40, 41
Stress-strain diagram, 43
Surfaces, development of, 267-282
Swages, 12

TABLES, the use of, 283, 285
Tanks, caulking of, 217
Taper of punches, 210
Tee iron rings, lengths for, 262
Tees and angles, weight of, 348-352
— bending of, 138-140
— block for bending, 120
Telescopic plates, 268-272
— plating, 259
Temperatures, estimation of, 157
Temper test for steel, 51
Tensile test, 40
— test of iron plates, 46-48
— test of steel, 51
Testing materials, 40-57
Test pieces, 45
Tests, forge, for steel plates, 54, 55
— forge, for iron plates, 48
— for iron and steel, 33, 34
— of iron, tensile, 46-48
— of steel, tensile, 51
Thinning corners, 240
Tongs, 12, 13
Tool handles, 10, 11
Tools, 6-23
Trammels, 19
Trapezoids, 289, 293
Triangles, 288

Triangular irons, 65, 67
Tubes, flanging of, 194-198
— rig-up for welding, 182, 183
— welding of, 175-183
Types of riveted joints, 237-259

UNITED inches, 69
Upsetting ends for welding, 160, 168

VEE welds, 164, 165
Versed sine, method of obtaining, 270, 271
Volumes, 291, 292

WEIGHT of angles and tees, 358-362
— of bar iron and steel, 352-357
— of plates, 351
— of steel and hoop iron, 350-351
Weights, calculating for, 283-287
— comparative, 365
— estimating of, 283-294
Weld iron, 32
Welding, 152-153
— fire for, 153, 154, 168
— fire-hole ring, 158, 159
— foundation ring, 159-164
— furnace, 180, 181
— gluts for, 159, 164
Welding hammers, 328
— heat for, 156, 157
— mandrels for, 176, 179-183
— of manhole ring, 158
— portable anvil for, 181, 182
— tubes, 175-183
— tubes, rig-up for, 182, 183
— upsetting ends for, 160
Welds, cracks in, 179
— glut, 172, 173
— lap, 164, 175, 176
— scarfed, 158, 168
— vee, 164, 165
Wheel for dividing, 20
Working load, 42
Work marked to full size, 265
— prices for, 263, 264
— to mark out, 265-282
Wrought iron, 25
— method of production, 25-29
— piling of, 27, 28
— puddling of, 26-29
— want of homogeneity in, 29

YORKSHIRE plates, 48

ZED bars, 60, 65
Zone of sphere, 291

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